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DEVELOPMENT OF LIFE PREDICTION CAPABILITIES FOR LIQUID PROPELLANT ROCKET ENGINES

Task 4 Final Report

Post-fire Diagnostic System for the SSME

System Architecture Study

Contract NAS 3-25883

CR-187112

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Propulsion Division

DIAGNOSTIC SYSTEM ARCHITECTURE STUDY

FINAL REPORT

Development of Life Prediction Capabilities
for
Liquid Propellant Rocket Engines

Contract No. NAS 3-25883

July 31, 1991

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This final report describes the work performed under Task Order 4 of the Development of Life Prediction Capabilities contract.

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16. Abstract

The system architecture task (1) analyzed the current process used to make an assessment of engine and component health after each test or flight firing of an SSME, (2) developed an approach and a specific set of objectives and requirements for automated diagnostics during post-fire health assessment; and (3) listed and described the software applications required to implement this system. The diagnostic system described in this report is a distributed system with a database management system to store diagnostic information and test data, a CAE package for visual data analysis and preparation of plots of hot-fire data, a set of procedural applications for routine anomaly detection, and an expert system for the advanced anomaly detection and evaluation.

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1.0 INTRODUCTION

This report documents the work accomplished in the Diagnostic System Architecture Study (Task Order 4.0 of the Development of Life Prediction Capabilities for Liquid Propellant Rocket Engines program, Contract NAS3-25883).

The objectives of this task were (1) analyze the current process used to make an assessment of engine and component health after each test or flight firing of an SSME, (2) develop an approach and a specific set of objectives and requirements for computer automated diagnostic processing during the post fire health assessment, and (3) list and provide high level descriptions of the software applications which need to be developed.

The first two of these objectives were addressed in Task 1 of this study. Section 3 of this report discusses the current system of diagnostics, specific user requirements and the overall approach recommended to automate these user needs.

The final objective of the study was to describe the software required to develop this overall approach. This was accomplished in Task 2 and the results are discussed in Section 4 of this report.

Finally, a brief outline for the development and implementation of this system was prepared. Section 5 of this report describes a recommendation for the phased development, testing, and implementation of the system.

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2.0 SUMMARY

The diagnostic system architecture study was a four month effort which accomplished three major objectives. The three objectives were to (1) analyze the current process used in making an assessment of engine and component health after each test or flight firing of an SSME, (2) identify specific system objectives and an approach to the development of automated diagnostic processing during post fire health assessment, and (3) list and provide high level descriptions of software applications needed to implement the approach.

The first objective was met through interviews with people who were or are currently involved in post-fire health assessment of the SSME. Analysis of the current procedures used to make health assessments and specific system requirements were formulated. The source and attributes of the data used to make health assessments were traced and the procedures, (both manual and computerized) which are used to generate and present the diagnostic evaluations of engine and component health were observed and documented. Figure 2-1 describes the current overall process of post test health assessment of the SSME. Figure 2-2 shows the current computing environment used for post test diagnostics.

The second objective was the development of an approach to enhance the diagnostic process by applying automated diagnostic tools. Figure 2-3 summarizes the distributed architecture of the recommended system. This architecture was designed to solve problems observed in the current diagnostic procedures and to address specific user requirements and desired functionality. The distributed architecture of the system allows the utilization of both the existing computer systems and the hardware upgrades (i.e., the Sun workstations and VAX 6320) planned under the Life Prediction contract and at MSFC.

The third objective of this study was the identification, organization and description of the software required to implement this approach. Figure 2-4 summarizes the software modules and applications required for implementation of the system. The complete diagnostic system is organized into five major modules which provide management and integration of the various data sources, statistical analysis and graphical presentation of the hot fire data data, automated data evaluation, expert-system based health assessments, and utilities for system administration and maintenance.

Finally, a brief outline for the development and implementation of this system was prepared. Figure 2-5 shows a scheme for the phased implementation of these capabilities.

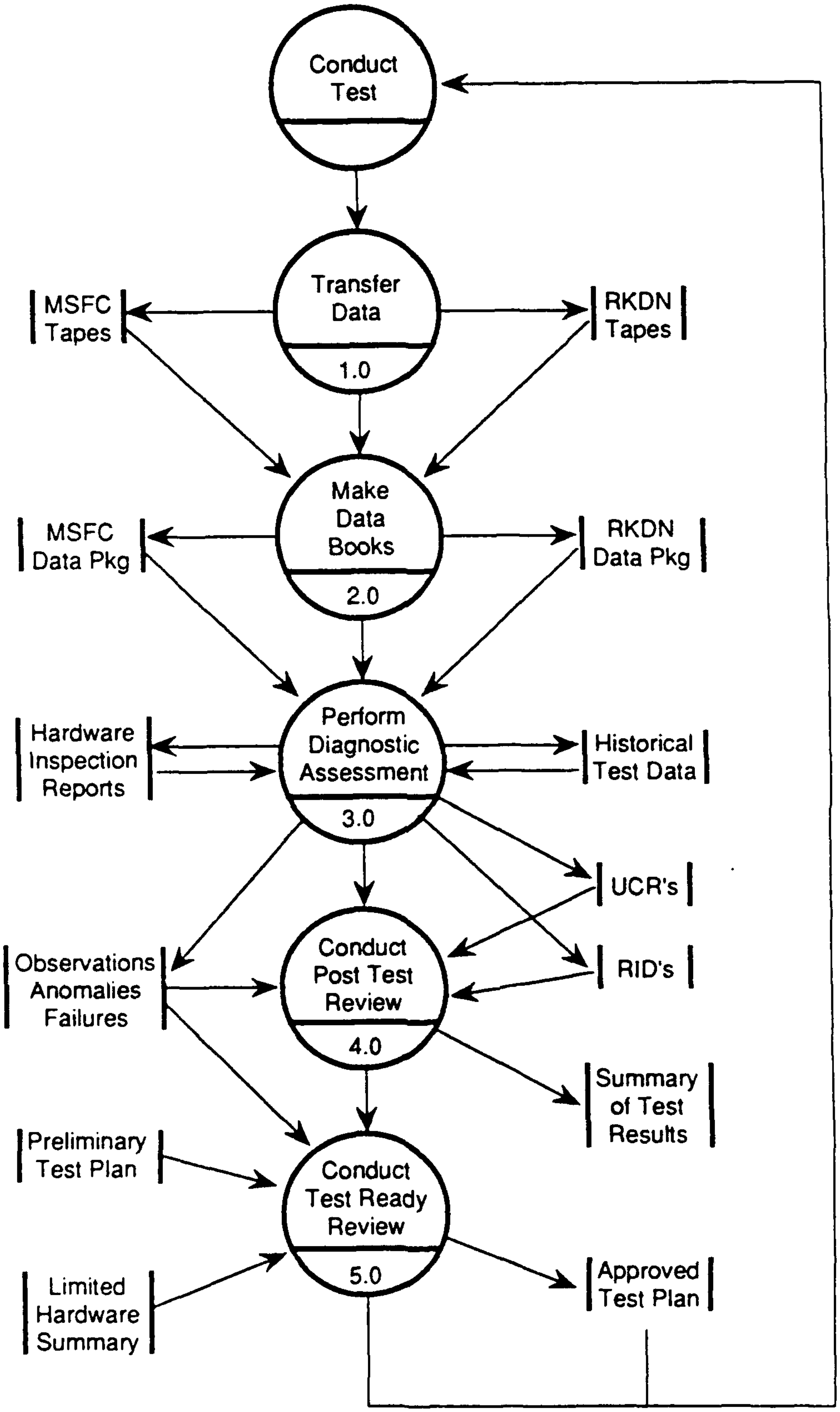

FIGURE 2-1 The Overall Process of Post Test Diagnostic Assessment

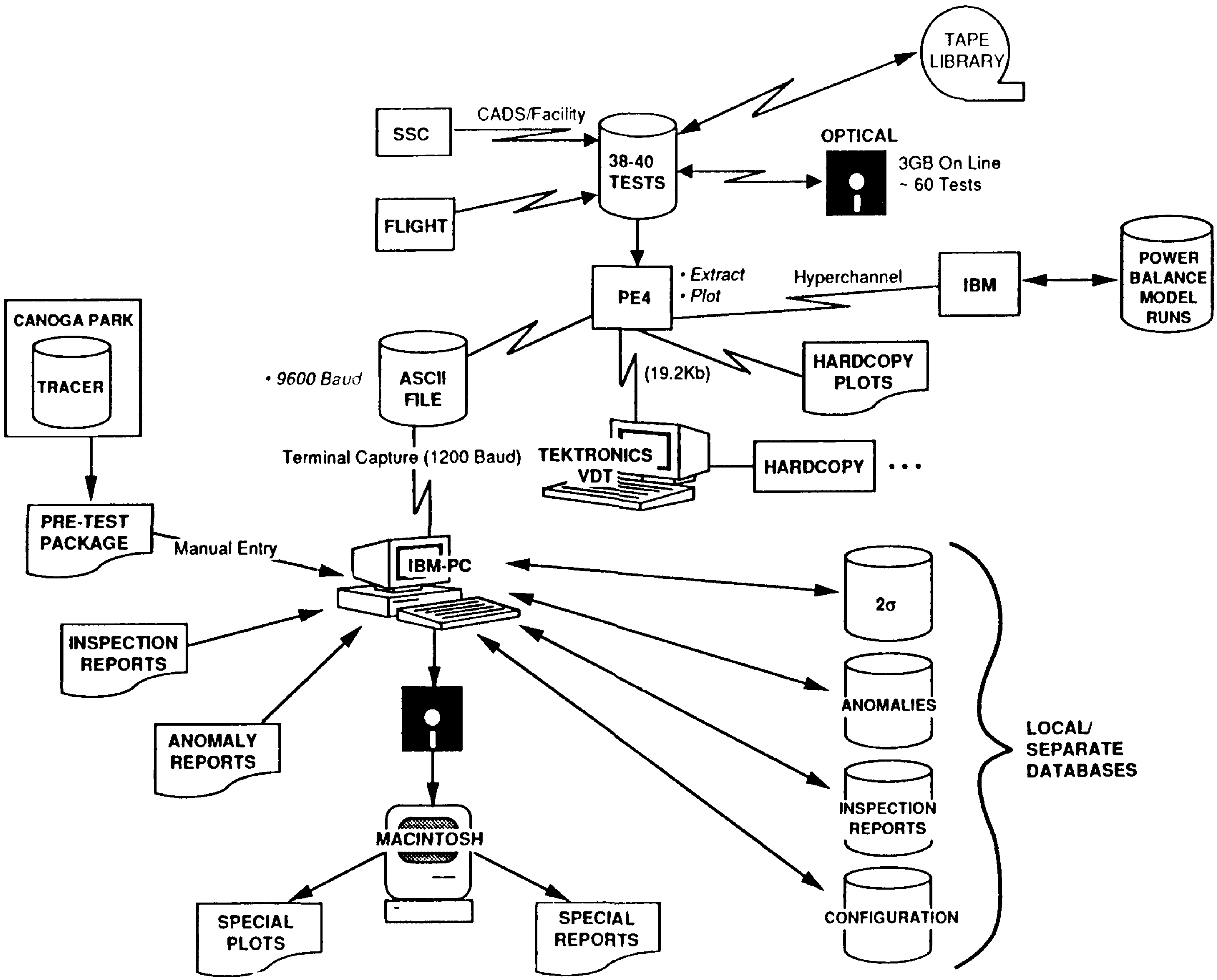

FIGURE 2-2 Current Computing Environment for Post Test Diagnostics

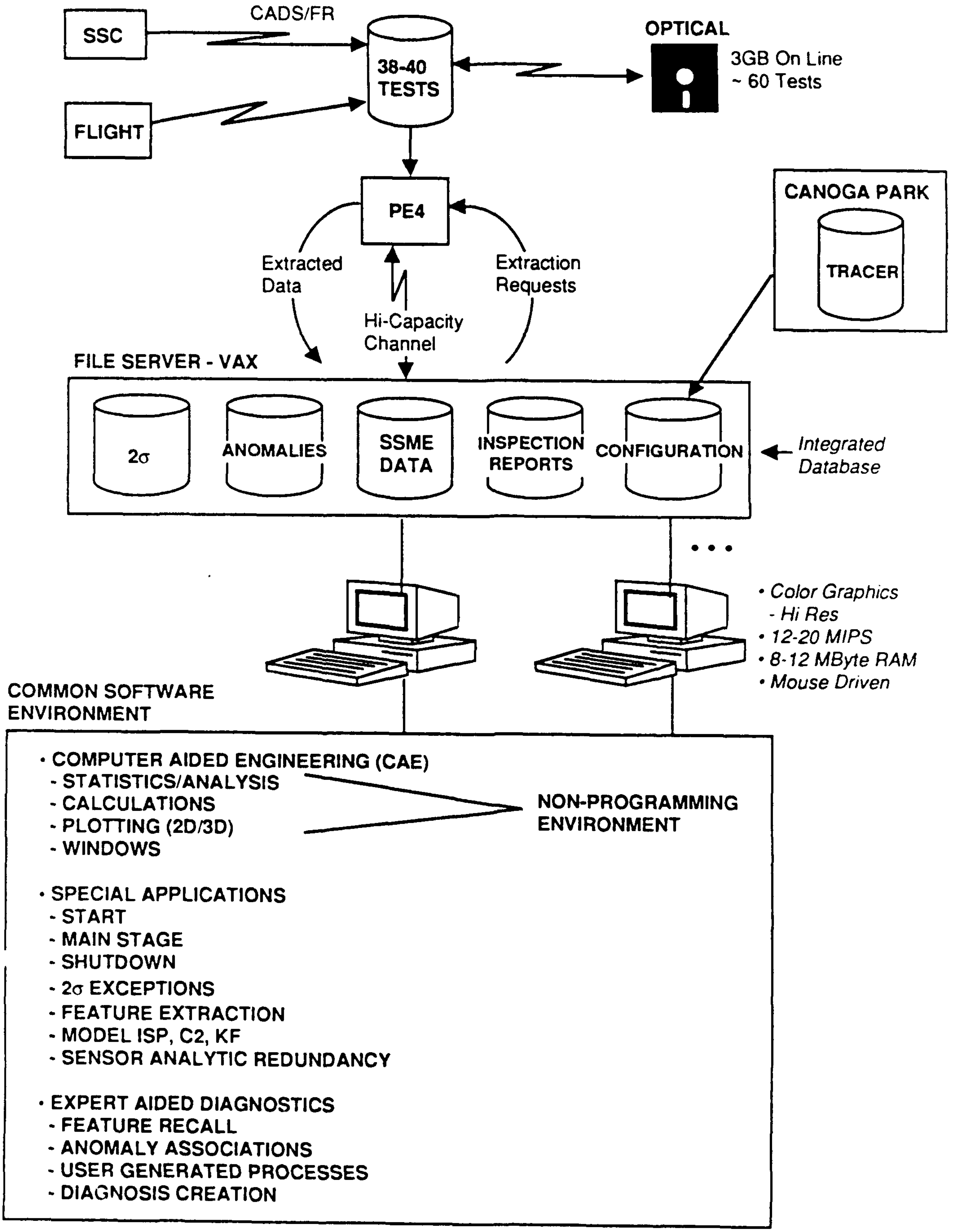

FIGURE 2-3 **The Proposed Diagnostic System Will Be Built On Planned MSFC Computer Upgrades**

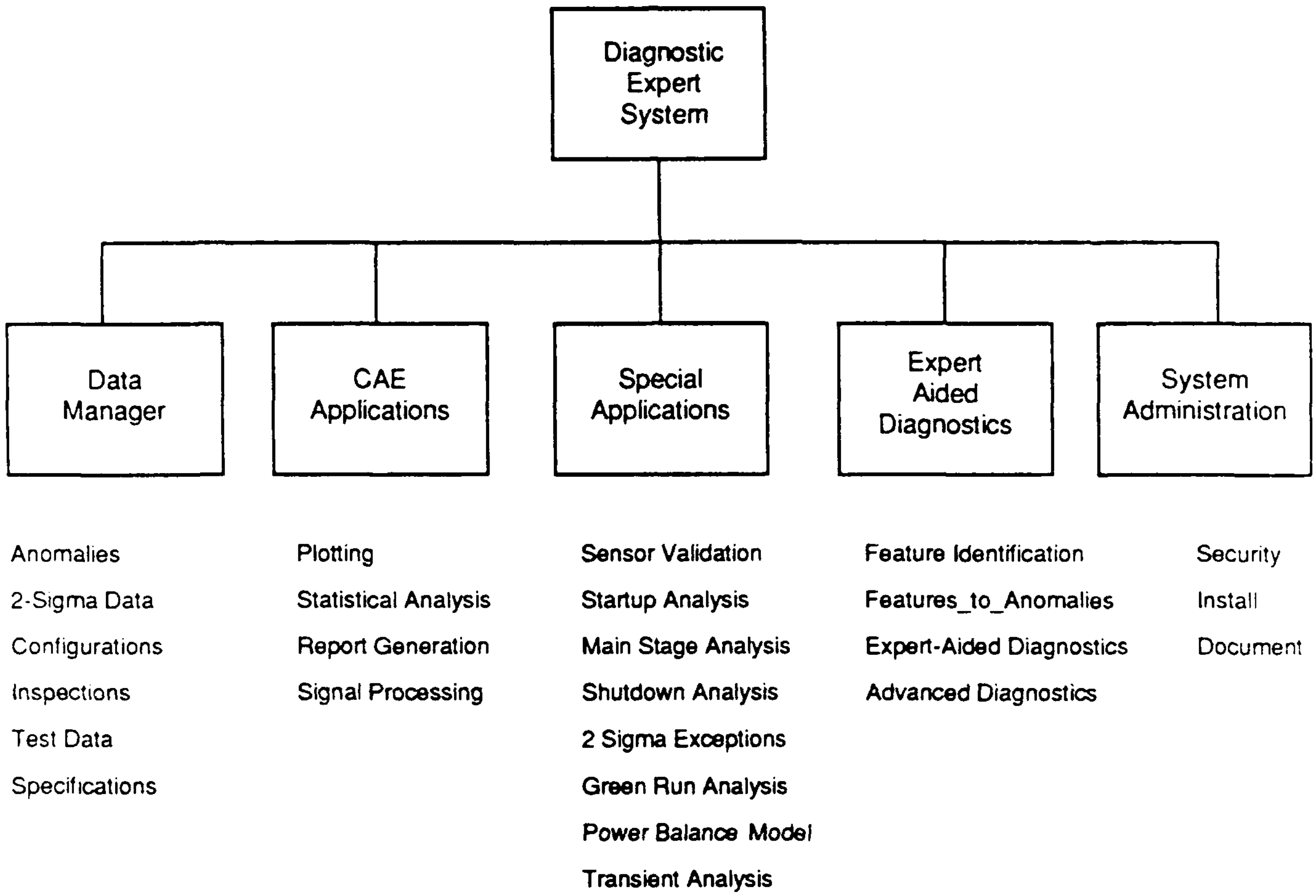

FIGURE 2-4 Overall Organization of Diagnostic System

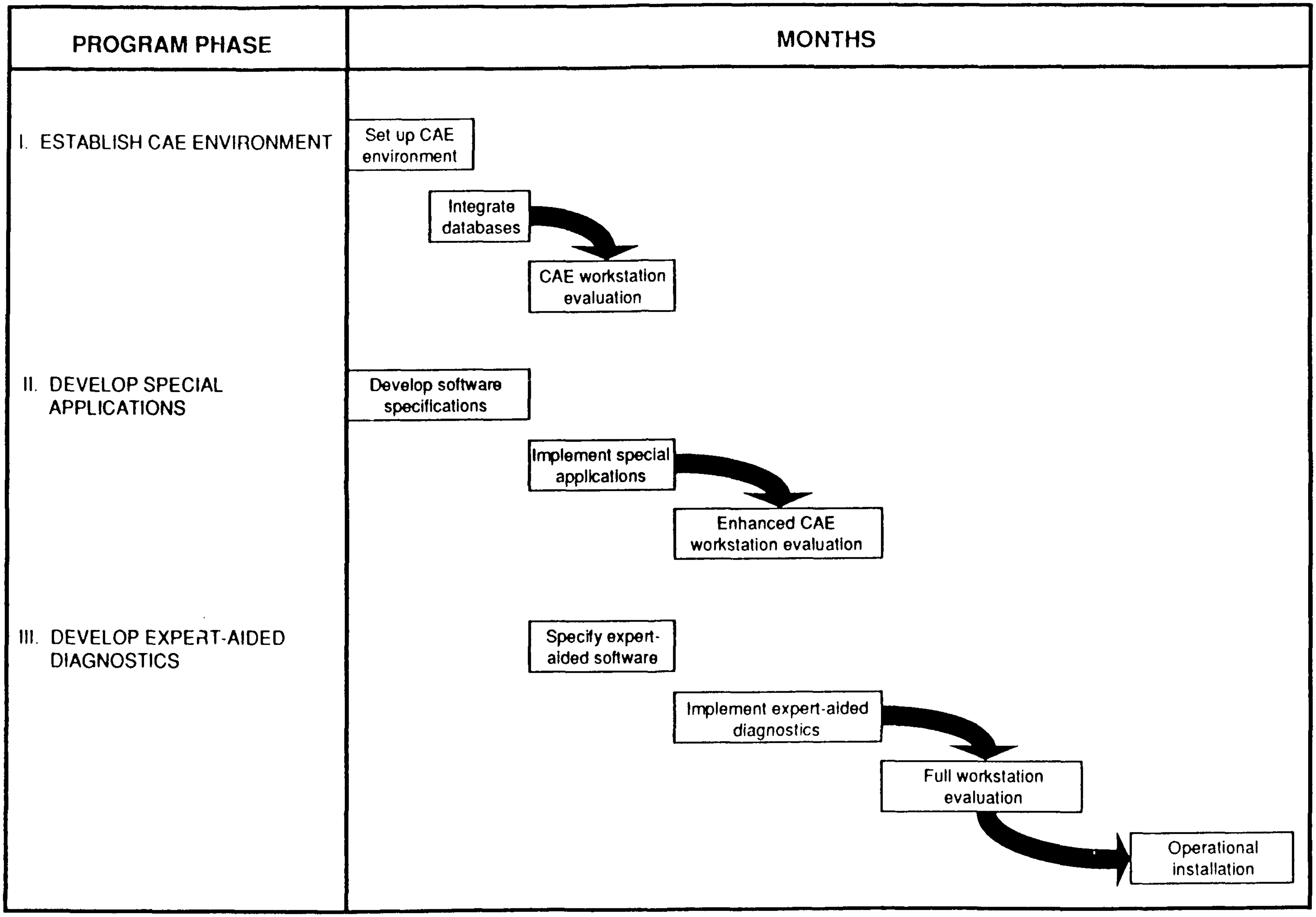

FIGURE 2-5 Health Assessment Workstation Implementation Plan

3.0 TASK 1 - SELECT APPROACH

3.1 INTRODUCTION

This section of the report presents an analysis of the current approach to post fire diagnostics and health assessment. Specific areas of the current system which may be improved through the application of intelligent automated tools are identified and discussed. Finally, a conceptual design for an automated system to aid the diagnostic process is presented and specific uses and benefits of the system are detailed.

A detailed understanding of the current diagnostic procedures and data flow came through discussion with people involved in post fire diagnostics of the SSME. This list of experts included personnel from NASA-MSFC, NASA-LeRC and NASA contractors from Martin Marietta, Aerojet, Boeing Computer Services, and Rocketdyne. Many of these people were interviewed in person during a trip to NASA-MSFC, which provided an opportunity to observe first hand the diagnostic process and current data handling procedures.

From these interviews, specific user requirements emerged. Each person interviewed was given the opportunity to describe computer-based tools which they would find useful during post fire data evaluation. More often than not, they had some very firm ideas of what they wanted and needed.

A conceptual approach was developed integrating these new capabilities with enhancements to the current system. This contrasts with providing a totally independent and isolated diagnostic system. The approach utilizes NASA's current and to-be-delivered computer hardware and software. While at NASA-MSFC the conceptual design of the system was discussed with potential users and administrators of the system. In these meetings, the approach was well received and users confirmed that the approach was responsive to their objectives and requirements.

3.2 CURRENT DIAGNOSTIC PROCEDURES

During our analysis of the current approach to post fire diagnostics, emphasis was placed on the evaluation of test (as opposed to flight) data because evaluation of test data is the larger job with more potential operations cost benefit. There are two reasons for this. First, more data is evaluated from the test stand than from the flight engines because there are many more engine tests than orbiter flights. Second, the instrumentation set is larger on the test stand than on the flight engines. This enables diagnostic evaluations and special studies based on test stand data which are not otherwise available from flight data. Still, there are many similarities in the procedures and techniques used to evaluate flight data, and it is safe to say that a diagnostic system which can effectively aid the evaluation of test stand data can also be applied to the analysis of flight engine data.

The procedures used during post fire diagnostics have evolved with the SSME and have become efficient through repetition, discipline, and the dedication and enthusiasm of the individuals involved. During this evolution, a number of guidelines have remained constant which must be recognized in any attempts to improve the system. One of these guidelines is that no tests are conducted until the data from previous firings has been thoroughly reviewed and evaluated. This imparts a severe time constraint on the evaluators. Post test diagnostics and health assessments are often started and completed within 24 hours of a test firing. Frequently, all instrumentation traces are reviewed and diagnostic conclusions formally presented within the same workday.

A second guideline used is that independent, corroborative assessment of the data be performed. This extends throughout the organizations which evaluate the data. At the highest level, teams from Rocketdyne and MSFC make independent evaluations of the test data. Within each diagnostic team, independent analysis and evidence is presented by the test engineers on turbomachinery, dynamics, combustion devices, and systems groups. The principle of independent corroboration of the diagnostic conclusions is maintained in all cases. Figure 3-1 presents the structure of the organizations which support the post fire data evaluations.

Figure 3-2 shows the overall post test diagnostic cycle for the SSME. Each circle is numbered indexing it to more detailed diagrams shown in subsequent figures. The focus of this program will be in defining and improving process 3.0 which is titled "Perform Diagnostic Assessment." This is the process where four major groups analyze the data determining if the test objectives were met and if there were any observations, anomalies, or failures which may impact the readiness of the engine for subsequent tests. However, to fully analyze the diagnostic process, and to enable improvements in the system, the other processes, particularly numbers 1.0 and 2.0 of Figure 3-2, were also examined in detail. In these processes, data is transferred from the test stand and compiled into the test data books.

Figure 3-3 shows some details of the process used to transfer data from the test stand to the data processing center at Marshall Space Flight Center. Separate recording systems are used to capture the CADS, Facility, and Analog data. After the digital sets (CADS and Facility) are converted to engineering units, they are transferred via telemetry to a Perkin Elmer computer (PE4) at MSFC. In parallel, the analog data is digitized and telemetered to the same PE4 system at MSFC. Analog tapes are also available for processing on one of two Masscomp computer systems separately administered and maintained by the Dynamics group.

The PE4 system is capable of storing up to 38-40 tests of CADS and Facility data and one (1) test of transformed analog data on line. Tape backups are archived for each set of test data. Administration and maintenance of the PE4 system is performed by contractors from NTI.

Once the data has been received and backed up at MSFC, contractors from Boeing Computer Services make the test data books (process 2.0 of Figure 3-2). At the heart of this process is a FORTRAN program on the PE4 called Plot. This program is used to construct a standard set of graphs showing a sensor value versus time. The test data books are complete by the beginning of the day after a test. Special plots, such as expanded scales on one or more axes, or plots of one sensor against another are constructed upon special request to the Boeing support personnel, or by an interactive session with the Plot program. Presentation quality charts with annotation or regression fits of the data are constructed by downloading selected data via modem from the PE4 to a PC or Macintosh. DeltaGraph, a Macintosh statistics/graphics package, is used to construct these presentation quality charts.

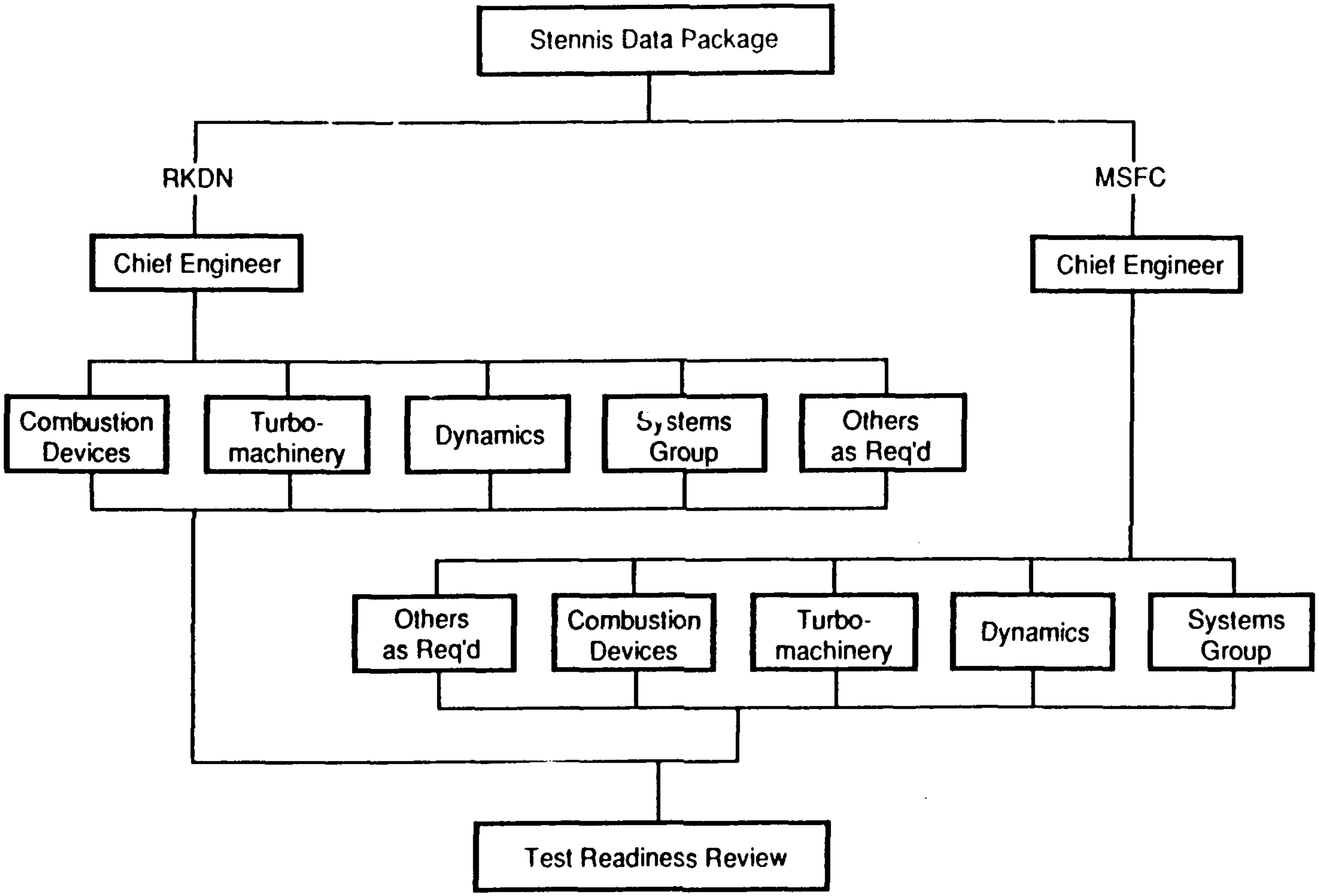

FIGURE 3-1 Organization of Post Test Diagnostic Teams

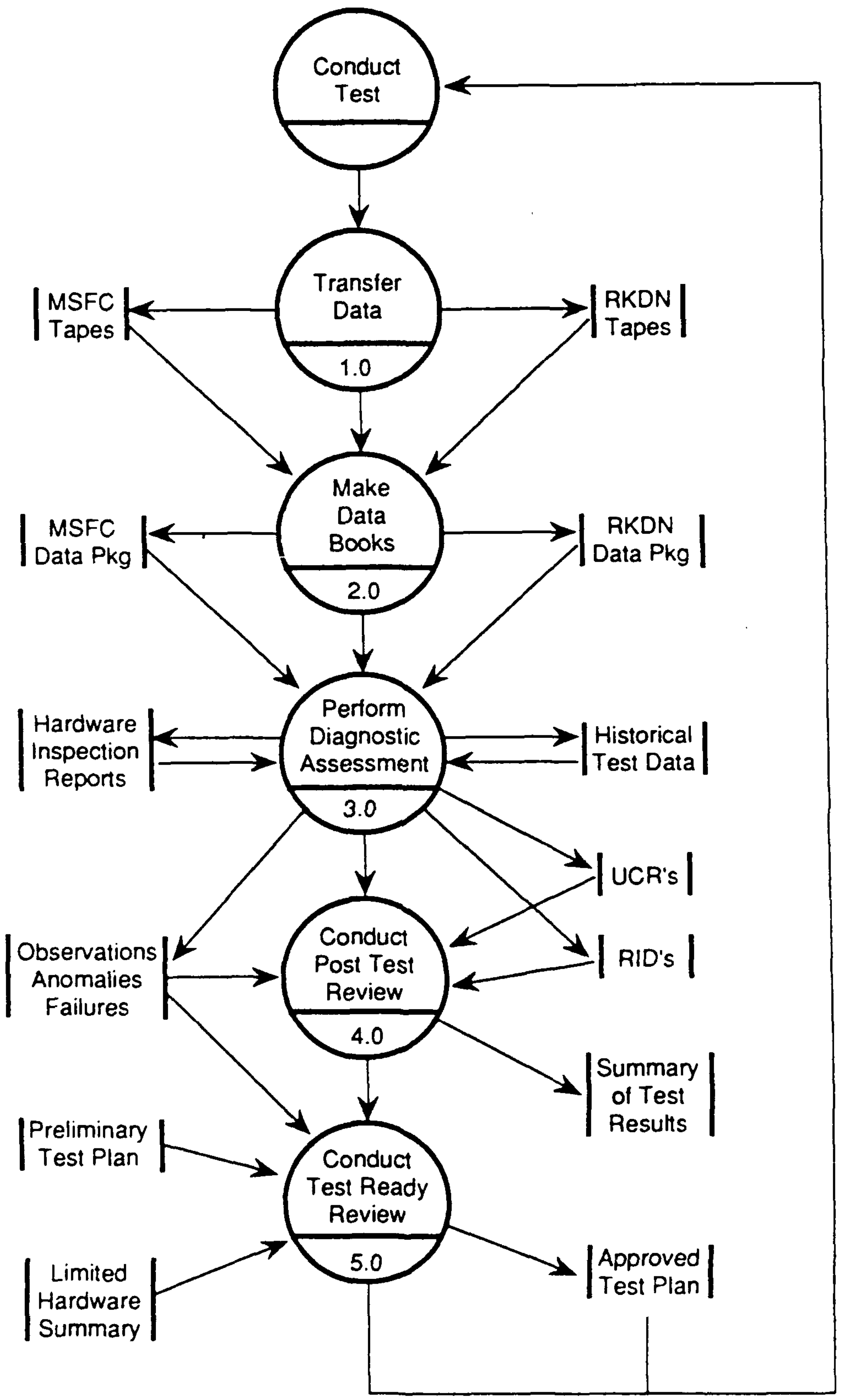

FIGURE 3-2 The Overall Process of Post Test Diagnostic Assessment

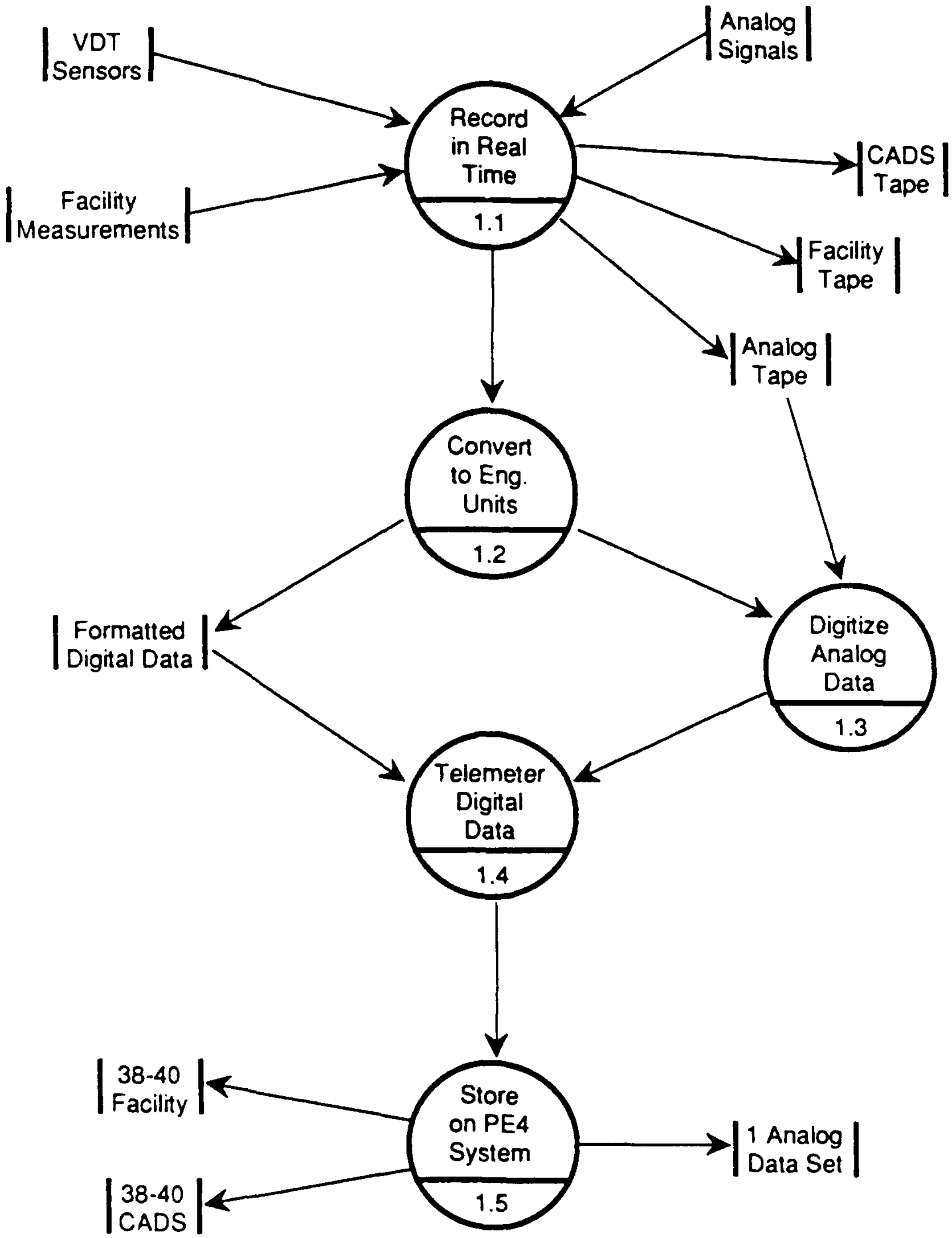

FIGURE 3-3 Transfer of Data from Test Stand to MSFC

Experts from each of the four major disciplines shown in Figure 3-1 evaluate the data contained in the test data book (process 3.0 of Figure 3-2). Possible sensor failures are identified by visual examination of the temporal plots and are then discussed and resolved with instrumentation specialists. Unexpected observations or anomalous engine behaviors are also identified through visual inspection of the temporal plots. Experts from each discipline consult with one another, or with test engineers at Stennis Space Center when an unusual data trace is observed. Results from manual post test inspection of the hardware are available, but not normally consulted unless an observation is made from the data traces or an unsatisfactory condition is observed during the inspection. Access to historical sensor data is generally limited to two previous cases which are presented with the standard data plots. *Previously observed failure signatures are not generally available and are recognized only through the experience and expertise of the individual evaluators.*

Unusual occurrences or performance outside the relevant specifications are recorded via the UCR or RID systems. These test events are formally discussed internally at the post test data review and externally with Rocketdyne at the Pre-Test Readiness Review. Conclusions from evaluating of the test data are recorded in a test summary prepared by the Systems Group.

The Systems Group at MSFC has taken responsibility for maintaining historical test records. They prepare the test summary for each hot fire test which is a compilation of selected plots from the test data book. In addition, they maintain databases on an IBM-PC which records hot-fire test descriptions, engine hardware configurations, test anomalies, descriptions indications, resolutions and results of inspection reports, and statistical 2-sigma bands around sensor values recorded at various steady state operating points. These applications are all independent of one another and the data is entered and updated manually.

Figure 3-4 shows a schematic of the overall computing environment used for post test diagnostics by the engine Systems, Combustion Devices, and Turbomachinery groups at MSFC. Shown on this figure is the Perkin Elmer 4 system which is used to receive, store and archive the test data, the Tektronics terminals which supports past test analysis and the modem links to IBM-PC and/or Macintosh computers.

3.3 USER OBJECTIVES AND REQUIREMENTS

This section describes potential improvements to the current diagnostic process through the use of automated tools. It is not intended to criticize the diagnostic teams or process at MSFC. Indeed, the greatest asset of the current diagnostic system is the quality and dedication of the people who process and evaluate the test data. Rather, this section of the report will focus on areas of the diagnostic process for which significant benefit can be realized through automation.

As discussed in the previous section, the current diagnostic process consists of five distinct steps. These steps are 1) Transfer Data, 2) Preparation of Data Books, 3) Conduct Diagnostic Evaluations, 4) Post Test Data Review, and 5) Test Readiness Review. Difficulties associated with each of these steps will be discussed.

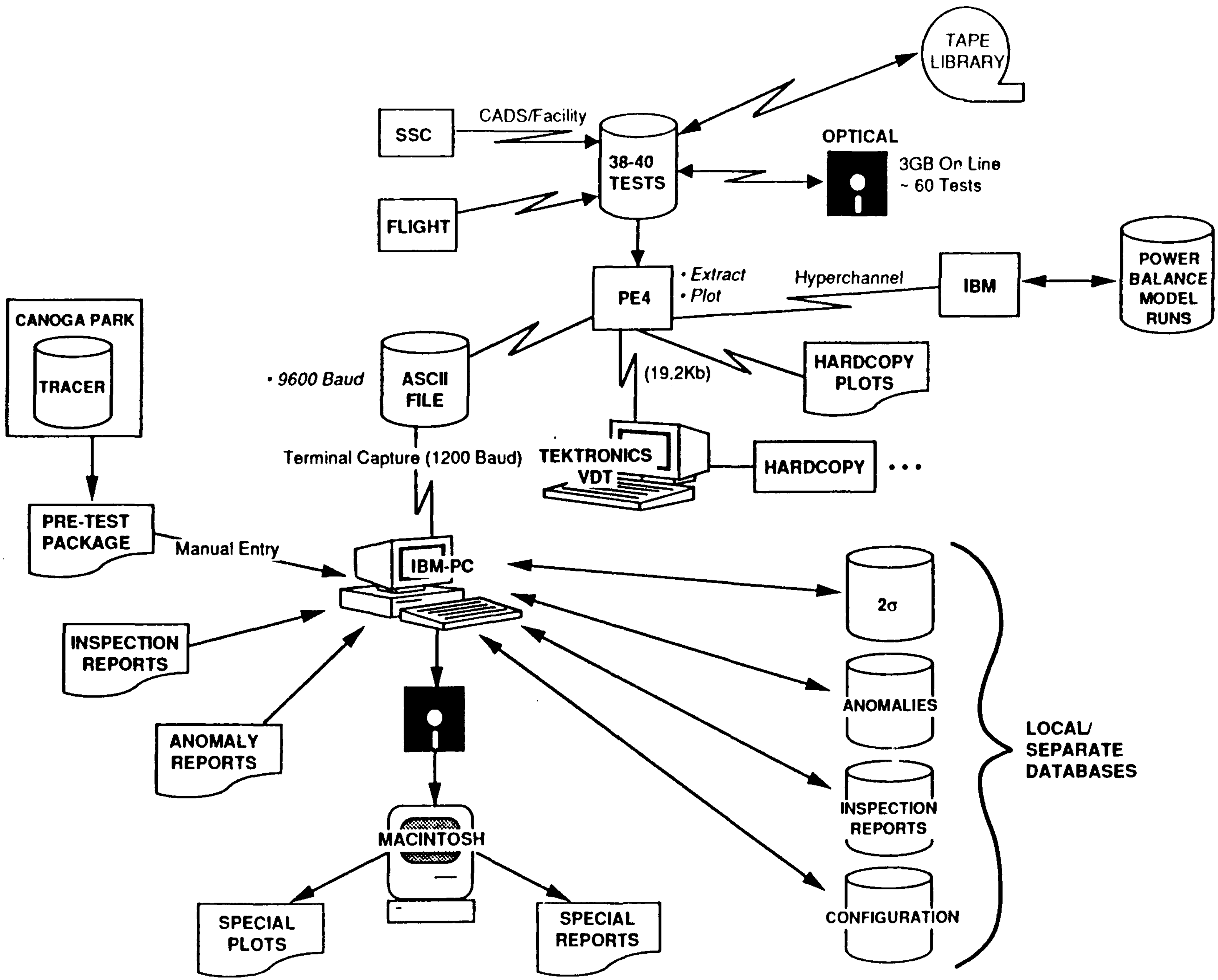

FIGURE 3-4 Current Computing Environment for Post Test Diagnostics

3.3.1 Transfer of Data

The recording and communications systems which captures and transmits the test data appear to be effective and reliable. The PE4 system and support staff are well established and adequately handle data receipt, on line storage and data archival. Particularly important is the PE4's ability to receive and record real time VDT transmissions from flight missions of the Shuttle.

The most significant limitation of the PE4 system is the limited storage of only a relatively small number of test cases. Only one (1) set of dynamics data are available on line. Additionally, up to 40 CADS and Facility sets (approximately 3 months worth of tests) are available at any given time. This storage issue is being addressed through the addition of optical disk drives. Although these drives are slow, they are capable of holding up to 60 additional tests of CADS and Facility data. The Dynamics data will soon be stored on two new Masscomp systems which will be supported by the Dynamics group.

This study does not recommend any significant changes to the current system of data transmission, storage, and archival. The current procedures should be used by the new Diagnostic System.

3.3.2 Preparation of Test Data Books

Production of the test data books is one of the major deficiencies which can be addressed through the use of improved automation tools. A number of specific problems in the current process are discussed below.

First, production of a test data book requires at least 4 to 5 hours. This is a major bottleneck in the diagnostic process which is currently addressed by assigning production personnel on off shifts to producing the book. One reason the production requires so much time is that each data book contains approximately 300 separate plots of sensor values versus time. We have not explicitly identified the need for each of these plots; however, we sense from our interviews that a more refined construct of the data presented may reduce the number of individual plots required.

Second, the data books contain a very limited set of automated evaluations. No comparisons to standard acceptance specifications or even simple 2 sigma envelopes are presented. The individual evaluator is responsible for providing the other data necessary to identify relevant test events or anomalies.

Third, the program which generates the test data books (the Plot program) is not very powerful or flexible. The Plot program produces the data books by executing a runstream file (a macro-like file of keystrokes) which generates the standard plots. Only a limited number of standard plot formats are available and construction of new formats or data manipulations requires modification of the Plot FORTRAN source code. For this reason, Systems Group personnel more typically download the data through a modem and perform custom manipulations and/or presentations of the data using desktop computers.

Fourth, the Plot program allows no more than 1000 data points per curve. At the maximum sampling rate of 50 Hz, this is only 20 seconds of data from one transducer. If a larger data set is requested, Plot automatically skips intermediate points, and effectively plots the data at a lower frequency to limit the number of data points plotted. This sometimes eliminates fast, but important test events from presentation on the plots.

A description of how these deficiencies will be resolved by the Diagnostic System is included in Section 3.4 of this report.

3.3.3 Data Evaluation

Evaluation of the test data is the next step in the overall diagnostic process. In general, the diagnostic evaluations rely heavily on the experience and ability of the individuals performing the assessments. Standardization and methodical evaluation of engine performance historical trends or inviolate specifications are not emphasized. As a result, a reasonably high level of on-the-job training and experience is required for the production of accurate and consistent diagnostic evaluations. A number of specific examples from our observations at MSFC made this point clear.

First, very little automated evaluation of the data is currently performed. Direct, single sensor 2 sigma, green run, or acceptance specification violations are not automatically diagnosed and highlighted. Instead, manual evaluation of the test data reveals these direct violations.

Second, there is no formal catalog of historical observations of the engines and their data signatures. The Systems Group has recently started to maintain a local database of observed test anomalies and a verbal description of the supporting evidence. However, this database is not used to support the current diagnostic process because it contains a small number of failures with no unexplained observations from previous tests. Presently, when an anomaly or observation is identified in the current test data, reference to previous test(s) which were diagnosed with the same anomaly is accomplished through the individual's recollection. "I remember something like this happened about nine months ago," was a comment that started a search back through the test summary books for related historical evidence and failure signatures while we were at MSFC.

Third, there is little automated reference to the operating history of individual engines or components. Data from two selected tests are shown on most of the standard plots contained in the data book. Frequent changes in test objectives and engine configurations often make direct comparison of current test data with previous firings difficult. Still, important historical trends in the operation of engine components is frequently not included in the standard data package. Drawing upon a case observed at MSFC, test data was compiled which showed that over the three previous firings of an engine, there was an increasing trend in the cavity pressure outside the main chamber liner cooling channels (see Figure 3-5). This is a strong indication of a leak between the cooling channels and the liner closeout. The plot was compiled only after manual evaluation of the data trace from the third firing and it revealed an unusually high pressure in the cavity.

The operating history of individual engines or components would be useful to assess the operational life and firing history of engine components. The number of starts and seconds on bearing sets was of importance in trending turbopump bearing wear data. Currently this is tracked informally by the Dynamics group. Another example was a comment regarding data presented for a low pressure fuel pump, "Yes -- but doesn't this pump always run a little cool?" This started a long, unresolved discussion about the historical operation of the component. It was obvious that there was no single, direct way to answer this question. In fact current procedures would require queries of configuration data from TRACER to determine which tests used the turbopump in question. This would then be followed by manual review of the data from these tests.

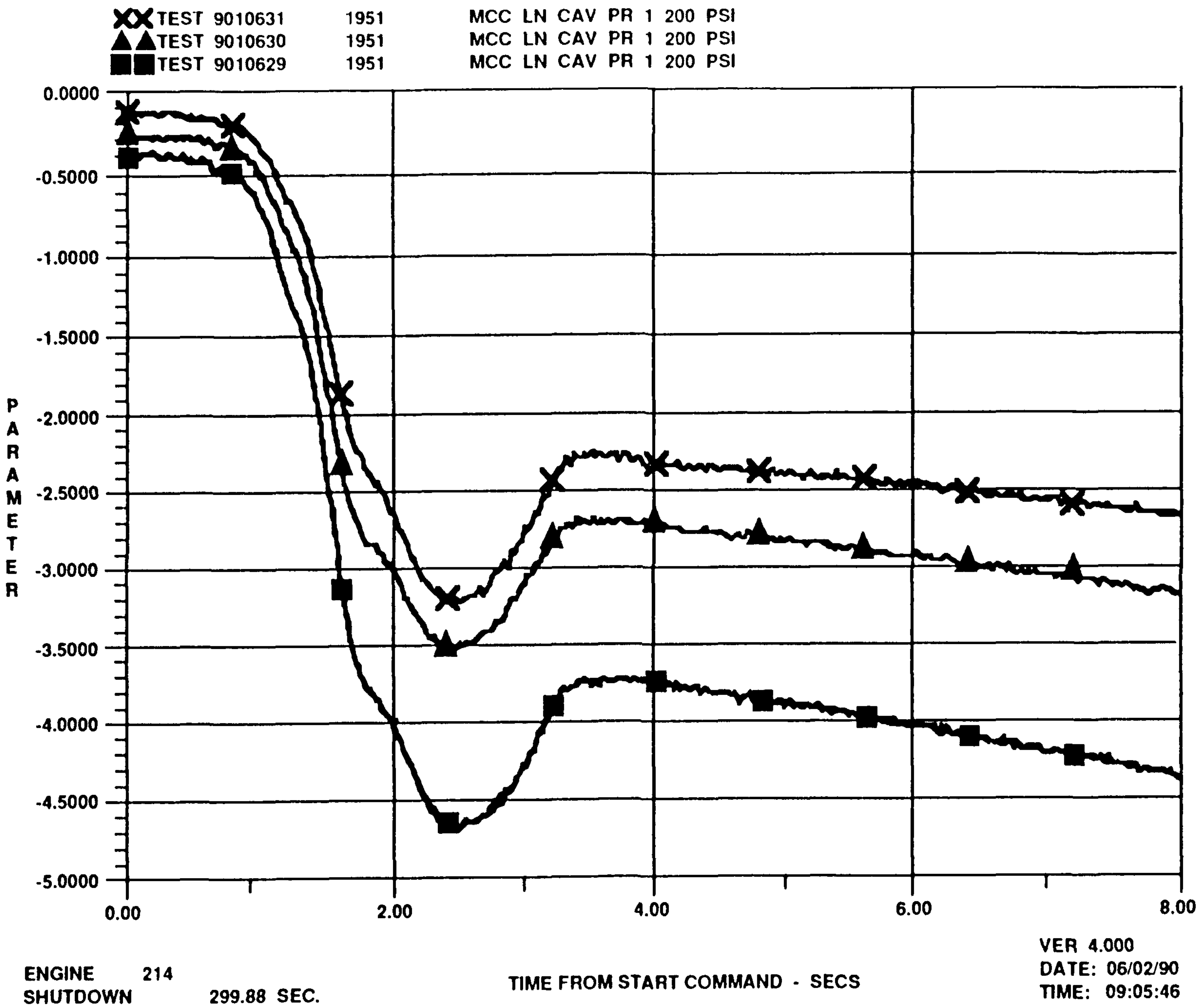

FIGURE 3-5 Liner Cavity Pressure Increased from Test to Test

3.3.4 Post Test Data Review

The problems observed during the post test data review were primarily a result of the deficiencies discussed in preparation and evaluation of the test data. Questions about the history of the engine components came up frequently and the discussions often ended without clear answers to the original query. Automated access to a historical test information database would significantly reduce these problems.

3.3.5 Pre Test Data Review

The problems observed during this part of the diagnostic process are primarily the result of deficiencies in previous steps. The major difficulty with this portion of the process is the difficulty personnel at MSFC have corroborating information presented by Rocketdyne. This was particularly evident in the discussion of DAR reports. DAR reports show the component history in terms of starts and seconds of hot fire life experienced on critical components for the upcoming test.

3.4 PROPOSED APPROACH

The proposed diagnostic system architecture has been designed with consideration to planned MSFC data processing capabilities. The software will combine existing (but currently separate) capabilities with new data analysis and expert aided diagnostics producing a fully integrated system hosted from an engineering workstation. We have evaluated the user benefits associated with the proposed implementation verifying the payoffs from each system component. We have developed an implementation plan for providing the workstation package to MSFC in an incremental fashion to quickly realize a portion of the benefits and provide an experience base which will help in completing the balance of the complex, expert system implementation.

3.4.1 System Configuration

The proposed workstation architecture will build upon the upgrades to the existing data processing network at MSFC (see Figure 3-6). MSFC is installing a VAX 6200 system linked to the Perkin-Elmer processor (PE4) over a high speed data link. Current MSFC plans call for the new VAX system to support multiple users at terminals throughout the propulsion laboratories. The VAX users will be able to generate requests to the PE-4 ADP staff moving test data from tape to disk or to automatically move test data from optical media to high speed disk. Data will be extracted from the PE-4 databases and moved to local VAX storage to assist in engineering analyses performed locally.

The proposed software architecture will use a portion of the VAX disk storage system for a local, integrated database of SSME test data and along with other historical and configuration information. These integrated databases will be accessed by a network of data analysis workstations which will be interconnected on the existing LAN and use the VAX as a file server. To workstation users, the system will appear as a distributed database managed by the INGRES database manager. Access times for the workstation users should be excellent based on the high performance of the VAX disk drives and DECNET LAN. Thus, the actual data residency will be invisible to the workstation users. The local workstation disks will be sufficient for temporary and user generated data storage along with storage of local software applications as required.

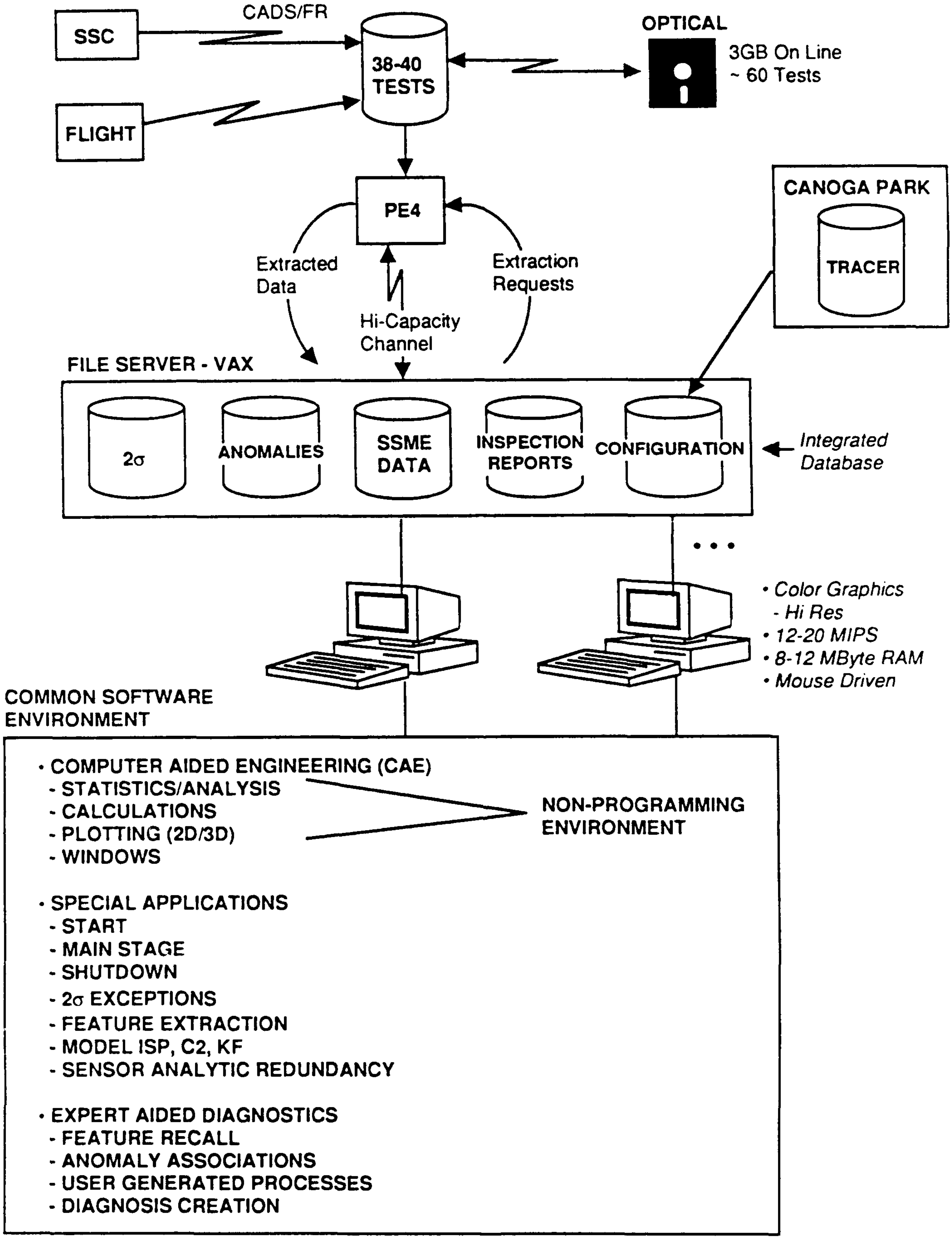

FIGURE 3-6 The Proposed Diagnostic System Will Be Built On Planned MSFC Computer Upgrades

The workstation hardware will be based on a RISC implementation. The workstation will have integer performance in excess of 12 million instructions per second (MIPS) and floating point performance in excess of one million double precision operations per second (LINPACK). It will provide a minimum of 8 MBytes of RAM and a 64 KByte cache to increase throughput. The workstation connection to the DECNET/Ethernet LAN will operate at 10 Mbits/second. The local mass storage will be in excess of 100 MBytes of SCSI hard disk storage with 22 milliseconds average seek time and 1.2 MBytes/second transfer rate. There will be a large, color graphics monitor with optical mouse. The operating system will be a UNIX-based multi-tasking window system with pull-down menus enhancing the user interface and reduce training requirements.

Implementation of the full expert-aided diagnostic system will require four to eight workstations networked into the VAX file server. The current architecture being implemented by MSFC will permit this without difficulty.

3.4.2 Proposed Software Functionality

3.4.2.1 Integrated Database Environment

3.4.2.1.1 Maintain SSME Test Database

These applications will transfer SSME test data from the PE4 computer into the file server database. The application will allow sufficient flexibility to transfer all or part of the test time and all or part of the engine's sensor set at various sampling rates.

Requests to the PE4 operators to move the test database from tape or from optical storage will be created as required. The data will be transferred over the high speed data link using the file transfer protocol best suited for the data, e.g., TCP/IP. File compression/decompression will be performed if beneficial to the overall efficiency of the process.

Data will be loaded into the integrated database on the file server and indices created for access. These applications will allow the user to manage test data stored on the file server including record display, deletion, editing, etc.

3.4.2.1.2 Maintain Anomaly and Incident Reports

Applications will be provided to store anomaly data derived from previous test reviews into an integrated database. This information will include narratives describing anomaly characteristics, causes determined, and identifying sensors. In addition, data traces showing the anomaly signature may be incorporated into the data record. The anomaly will be represented with a group of sample data traces from involved sensors or, more generally, using feature descriptors such as slope, level and duration of the response.

Records can be entered, deleted, edited and/or displayed. Data indices will include test number, date and affected engine components.

3.4.2.1.3 Maintain Two-Sigma Database

Applications will allow storage and retrieval of two-sigma data bands for start-up, mainstage and shutdown. The two-sigma bands will be available for plotting and comparison with actual test data. The bands will be updated with selected test runs on user request. New bands may be created for new or varied test scenarios. Applications will be provided to examine ensembles of test runs and extract the two-sigma data bands so that customized bands can be created for specific SSME configurations.

3.4.2.1.4 Maintain Configuration Data

Applications will enable tracking of the major SSME components' operating history. Since parts tracking is performed by the TRACER program, this application will principally download configuration data to the file server and provide a subset of the TRACER records for correlation during test data analysis.

In addition, an on-line query generator will be provided to automatically generate a TRACER data extraction for specific configuration requests. For example, if the installation history of a particular HPOP was required, the user would complete the several entries on a workstation form. The application would connect to the TRACER mainframe at Canoga Park, run the required job stream, recover the data and incorporate it into the database for inspection and correlation with test data.

3.4.2.1.5 Maintain Specification Data

Data on specification requirements will be maintained to aid in the automated evaluation of acceptance test and green run data. Data will reflect the minimum and maximum acceptable sensor values for all engine measurements called out in the applicable specifications. Storage of these values in the integrated database will permit automatic updates to the evaluation criteria if engine requirements or design changes affect the specifications.

Records can be entered, deleted, edited, and/or displayed. The specification data will be indexed on specification type, operating phase and sensor identifier.

3.4.2.1.6 Maintain Inspection Data

Data from each manual inspection of the engine are now maintained by the Systems Group. The data provides added evidence to evaluate hypotheses about observed test events. Inspection reports from previous firings of specific engine components are also used during post-test data reviews. Storage of these inspection reports in the integrated database will be helpful in supporting expert-aided automated diagnostics.

Records can be entered, deleted, edited, and/or displayed. The inspection data may be manually or automatically queried for specific test numbers, dates, LRU numbers, or by the identification of certain test events in the data.

3.4.2.2 Computer Aided Engineering (CAE) Environment

3.4.2.2.1 Plotting Applications

A comprehensive color data graphing application will allow test engineers to plot test information in a variety of formats. Test to test comparison, multi-variable plots, two-sigma overplots and other analysis requirements will be supported by the application in conjunction with the databases.

These applications will allow specific plots to be stored in the database. There will be an extensive range of standard chart formats including multi-plot, multi-line, bar, pie, 3-D, etc. Plot parameters or templates can be stored so that standard plot reports can be designed and created automatically when test data becomes available.

The plot applications will be based on third party graphics and data analysis packages suitable for the workstation. Over forty such packages were reviewed in Task 2 of this study. Section 4.3 of this report discusses this review and recommends seven candidates for further evaluation.

Minimal computer programming is required and the interface will use multiple windows with a mouse. Zooming will dynamically rescale local areas of the plot for closer examination under mouse control.

3.4.2.2.2 Data Processing/Statistic Applications

A general purpose computer-aided engineering (CAE) function will allow direct manipulation of data vectors by the user through non-programmatic mathematical expressions. The CAE function will support all types of signal processing and analysis techniques including digital filters, FFT, statistical filters (e.g., maximum likelihood, Kalman, etc.), dynamic modelling, regressions, ARMA, etc. Free form analyses by the user will be provided using direct mathematical expressions or predefined functions that operate on the data. Results will be expressed in a tabular or graphical output, or maintained as intermediate values in a multi-step analysis. These free form analyses will provide an additional basis for knowledge capture in the expert application.

3.4.2.2.3 Report Generation Application

An application will provide standard report formats which integrate graphical data presentations with text from related databases or manual input. These reports can be automatically produced when a specific set of flight data are studied for test evaluation and health assessment. The reports will be user generated and easily modified to support unique investigations.

3.4.2.3 Special Applications

3.4.2.3.1 Sensor Validation

An application (developed under a separate task) will provide sensor validation. Test data sequences will provide the input to the program determining indications of faulty sensors. Sensor faults such as bias shift, scale factor error, noise, and environment-caused errors will be addressed by the package. In addition to the error indications, an estimate of the corrected sensor readings will be produced.

3.4.2.3.2 Start/Main Stage/Shutdown Analysis

The performance of the engine against the applicable ICD, Green Run, or Acceptance Specifications will be evaluated automatically. Exceptions to performance will be generated and form the basis for diagnostic analysis by the users and the expert aided system.

3.4.2.3.3 General (2-Sigma/Features) Exception Analysis

An application will automatically screen data sequences against two-sigma bands established for the specific test scenario. Exceptions will be generated to initiate diagnostic analysis and provide supporting information to the expert aided data analysis applications.

An application will automatically screen test phase data against feature descriptors for normal and anomalous behavior. SSME faults exist which do not cause exceedances of 2-sigma bands, but which exhibit either unusual or identified abnormal behavior. An example of this is fuel side oscillations which occasionally occur during shutdown. Exceptions to either two-sigma or normal feature definitions will be logged and recorded against the test sequences in question. Troubleshooting applications will use these indicators and the established diagnostic rule base to correlate identified exceptions with known failure modes.

3.4.2.3.4 Power Balance Model

The power balance model will be integrated into the test analysis environment. Averaged test data will be created for inputs and outputs relating to Kf's, etc., and will be incorporated into the test phase reports. The model will also be used for 2-sigma steady-state detection during specific test phases. Additional applications and special investigations will also be supported within the workstation environment.

3.4.2.4 Expert Aided Diagnostics

3.4.2.4.1 Maintain Diagnostic Rules (Anomaly Associations)

Diagnostic rules will assist the analyst in correlating observed indicators (data exceptions) with one or more previously identified anomalies. The anomaly database will be built from test experience and history. The inference process which links specific data exceptions with the abnormalities will be captured in the rule base. This function will capture the knowledge linking the exceptions with faults. The representation selected will recognize the attributes of the abnormality and search for matching indications in data. After analysis of the exception, the knowledge base will be updated automatically (under manual control) to capture the reasoning and outcome of the analysis so that it can be applied to future occurrences.

3.4.2.4.2 Perform Aided Diagnoses

This application will lead the user through a structured analysis of one or more abnormal indications. The inference structure represented in the knowledge base will be used as the basis for the analysis; however, at any time, the user can examine specific data on the current test and from prior occurrences of suspected anomalies.

The user's path through the inference process will be automatically captured by the system using the transaction log. This log will form the basis for rule-base updates using the expert system's knowledge maintenance tools. The application will allow partial diagnostics of multiple exceptions so that the user can combine conclusions between exceptions. The linking of multiple diagnostic goals is an inherent feature of the NEXPERT Object shell selected for the application.

3.4.2.4.3 Advanced Diagnostic Applications

Advanced applications will be integrated into the workstation data environment to support special investigations and advanced diagnostic development. The intent of the computing environment is to provide the flexibility to incorporate advancing capabilities rapidly and cheaply in an incremental manner. Advanced features may include deep-reasoning diagnostic systems which incorporate physical models of SSME faults and automatic knowledge generation/maintenance tools applicable to the problem.

3.4.3 Application Users and Benefits

We have partitioned the system into applications which support the various data users. For each application, there are one or more benefits that the new workstation implementation will provide. In Figure 3-7, we have compiled a list of the benefits of each application area and associated them with the user groups deriving the benefit. It is clear from the figure that there are several applications which will immediately benefit several user groups and that benefits will be provided at each level of system implementation.

APPLICATION	FUNCTIONALITY	BENEFITS	Data Group	Model Group	Dynamics	Turbomachinary	Combustion Dev	Data Services	Test Engineers
I. Database Maintenance Environment									
A. Maintain SSME Test Database	Move test data from PE4 to local file server and load into database.	Simplify data handling, decrease time lag for data availability and increase amount of historical data available on-line.	X	X		X	X	X	
B. Maintain Anomalies/Incident Reports	Create database on Incident/anomaly reports along with analyses results, data samples and features observed in the test.	Automate memory of past experiences, increase efficiency and productivity of test reviews, integrate all groups' knowledge into single repository, form basis of automated health assessment system.	X		X	X	X		X
C. Maintain Two-Sigma Database	Calculate 2-sigma bands for each test phase around sensor transient readings, maintain these data, and permit storage of multiple 2-sigma bands for user-defined, population subsets.	Quick look validity analysis for specific tests, increase efficiency of data handling for these calculations, automate pre-screening test using this data.	X			X	X		
D. Maintain Configuration Data	Import major component configuration history for test articles from TRACER and make available on workstations in conjunction with other data.	Improve ability to track major component performance histories, increase productivity of test reviews, allow easier comparison with past component test results, confirm usage data between NASA and Rocketdyne.	X	X	X	X	X		X

FIGURE 3-7 Post-Fire Health Assessment Workstation User Benefits

APPLICATION	FUNCTIONALITY	BENEFITS	USERS: Data Group	Model Group	Dynamics	Turbomachinary	Combustion Dev	Data Services	Test Engineers
II. Computer Aided Engineering (CAE) Environment									
A. Plotting Applications	Provide a variety of data plotting graphics in standard and custom modes including multiple plot windows, mouse control, 3-D, trends, etc.	Increase plot availability, increase flexibility in viewing data, increase user efficiency in plotting data, provide capability to correlate different types of data easily, increase number of plot types, increase user-friendliness over current process.	X	X	X	X	X		X
B. Data Processing/Statistic Applications	Provide CAE environment to operate on test data using non-programmatic, mathematical expressions.	Increase analysis efficiency, flexibility and productivity, increase ability to perform special studies, and increase utility of test data overall.	X	X	X	X	X	X	
C. Report Generation Application	Provide capability to generate standard reports including, but not limited to, standard plot packages.	Increase speed of plot package delivery, increase flexibility of report formats and content, improve efficiency of test reviews, increase accuracy of findings.	X			X	X	X	

FIGURE 3-7 Post-Fire Health Assessment Workstation User Benefits (Cont'd)

APPLICATION	FUNCTIONALITY	BENEFITS	Data Group	Model Group	Dynamics	Turbomachinary	Combustion Dev	Data Services	Test Engineers
III. Special Applications									
A. Sensor Analytic Redundancy	Determine sensor failures including bias, scale factor shift and noise and provide corrected values.	Improve test data analysis process by reducing effect of sensor anomalies on analysis process, increase accuracy, efficiency and productivity of data reviews.	X	X		X	X		
B. Start/Main Stage/Shutdown Analysis	Perform automated performance validation against test phase specifications for each test and flag unacceptable performance levels. Also, perform special performance studies as defined by users beyond test phase specifications.	Make test phase performance calculations uniform among tests and analysts, increase productivity by pre-screening test runs and increasing analysis accuracy using automated processes.	X		X	X			
C. General (2-Sigma/Features) Exception Analysis	Perform pre-screening of sensor channels against 2-sigma bands, customized to test phase and perhaps test article.	Increase efficiency of analysis process by identifying areas for analysis automatically, increase analysis accuracy by providing automated checking of data.	X		X	X			
D. Power Balance Model	Integrate power balance model into data environment permitting running on averaged test data directly from test database.	Increase efficiency of power balance running, decrease steady state data handling, integrate power balance results more closely with transient data.		X					
E. Transient Model									

(USERS heads the user columns, Data Group through Test Engineers.)

FIGURE 3-7 Post-Fire Health Assessment Workstation User Benefits (Cont'd)

APPLICATION	FUNCTIONALITY	BENEFITS	USERS: Data Group	Model Group	Dynamics	Turbomachinary	Combustion Dev	Data Services	Test Engineers
IV. Expert Aided Diagnostics									
A. Maintain Diagnostic Rules (Anomaly Associations)	Establish knowledge base which relates anomalous indications to specific hardware/test failures stored in Incident/anomaly database.	Increase accuracy, efficiency, and productivity of test analysis process by capturing expertise developed during test program and applying it to future testing.	X	X	X	X	X		X
B. Perform Aided Diagnosis	Use knowledge base and incident indications to perform diagnosis of test results and link observations established anomalies or new failure modes.	Increase efficiency of test analysis, decrease learning period for new analysts, increase accuracy of test analysis process using automated tools.	X		X	X	X		
C. Advanced Diagnostic Applications	Allow for incorporation of advanced diagnostic procedures into workstation environment.	Increase utility and life-cycle of workstation by allowing incremental growth, increase utility by permitting special studies easily and quickly.	X	X	X	X	X		X

FIGURE 3-7 Post-Fire Health Assessment Workstation User Benefits (Cont'd)

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4.0 TASK 2 - SYSTEM DEFINITION

4.1 HIGH LEVEL ORGANIZATION

This section describes the software required for an automated system to perform post fire diagnosis and health assessment of the SSME. The system is designed to meet the user requirements and provide the benefits discussed in section 3.0 using a distributed architecture approach.

Figure 4-1 maps the logical organization of the system. The system requires database management, CAE capabilities for data manipulation, presentation and plotting, special applications for specific data evaluations, and expert systems (under the Nexpert Object Expert System Shell). Procedural portions of the code will be written in C.

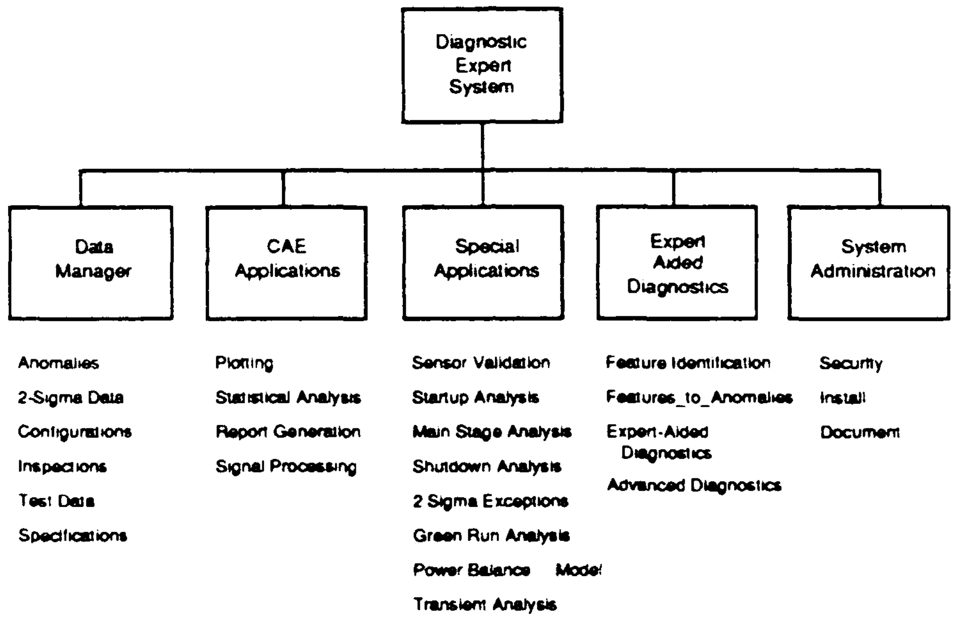

FIGURE 4-1 Overall Organization of Diagnostic System

The executive program provides the primary user interface for these system and will reside on a Sun workstation. The workstation will in turn generate requests for data and/or calculations on one or more of the other systems (VAX, PE-4, and IBM) as required using the existing LAN at MSFC. These requests and the background processing will be made transparent to the user.

Data used by the system to make diagnostic evaluations will be stored on the VAX 6320 at MSFC under the Ingres relational database management system. Specific database structures and attributes are described in section 4.2 of this report.

Presentation and analysis of data will be accomplished with the aid of a commercial analysis, graphics and statistics package. Over forty commercial packages were examined during the course of this study and a list of eight packages has been recommended for further evaluation. Section 4.3 of this report discusses both the use of CAE packages within this diagnostic system and examines the capabilities of the packages.

Diagnostic evaluation and analysis of hot fire data is conducted in two areas of the system. The first of these is called the special application module. The second is called the expert-aided diagnostic module. Classification of the diagnostic applications into one of these two areas is preliminary. For example, there is some merit in classifying the program which analyzes hot fire data against the green run requirements as an expert system diagnostic. However, we have chosen to classify it as a special application because the green run evaluation criteria is relatively straight-forward and does not require heuristic reasoning or interpretation based on experience.

The special applications module, then, is a collection of diagnostic routines that are primarily procedural in nature. These evaluations are currently performed in a relatively structured and repeatable manner during the course of the data analysis. Some of these special applications exist as stand-alone applications on MSFC processors (the PE-4, IBM mainframe or IBM-PC) and are currently supporting the diagnostic activity. Development efforts will be concentrated on making these individual programs work together within the integrated diagnostic system. Each special application is discussed in more detail in Section 4.4.

The expert-aided diagnostics module will use expert systems technology based on the NEXPERT Object shell to emulate the heuristic evaluations and health assessments currently performed by experienced engineers. A knowledge base will be constructed to automatically identify features (with a confidence factor) in the hot fire data. These features and confidence factors along with other information concerning the test, engine configuration, inspection reports, etc. will then be used to diagnose the cause of the anomalous behavior. Section 4.5 presents the applications and knowledge bases required for development of these capabilities.

4.2 INTEGRATED DATABASE

4.2.1 Application List and Outputs

The integrated database provides the foundation for the diagnostic system. The database consolidates information from sources which are currently disconnected. The purpose of the integrated database is to provide a consistent format and a universally available platform to all of the data which is relevant to the diagnostic process.

Six general categories of data were identified as important and useful in the diagnostic process. These categories are:

a. Engine Build Configurations & Operating Profiles (i.e., component history);
b. Identified Operating Anomalies;
c. Hardware Inspection Reports;
d. Statistical (2-Sigma) Norms;
e. Specification Requirements; and
f. Test or Flight Measurements (i.e., CADS, Facility, and Analog data).

This data originates from a variety of locales. The current data storage formats include from an IBM DB2 database, IBM-PC Symphony file to hand-written reports. The source of each of these data types are listed in Figure 4-2.

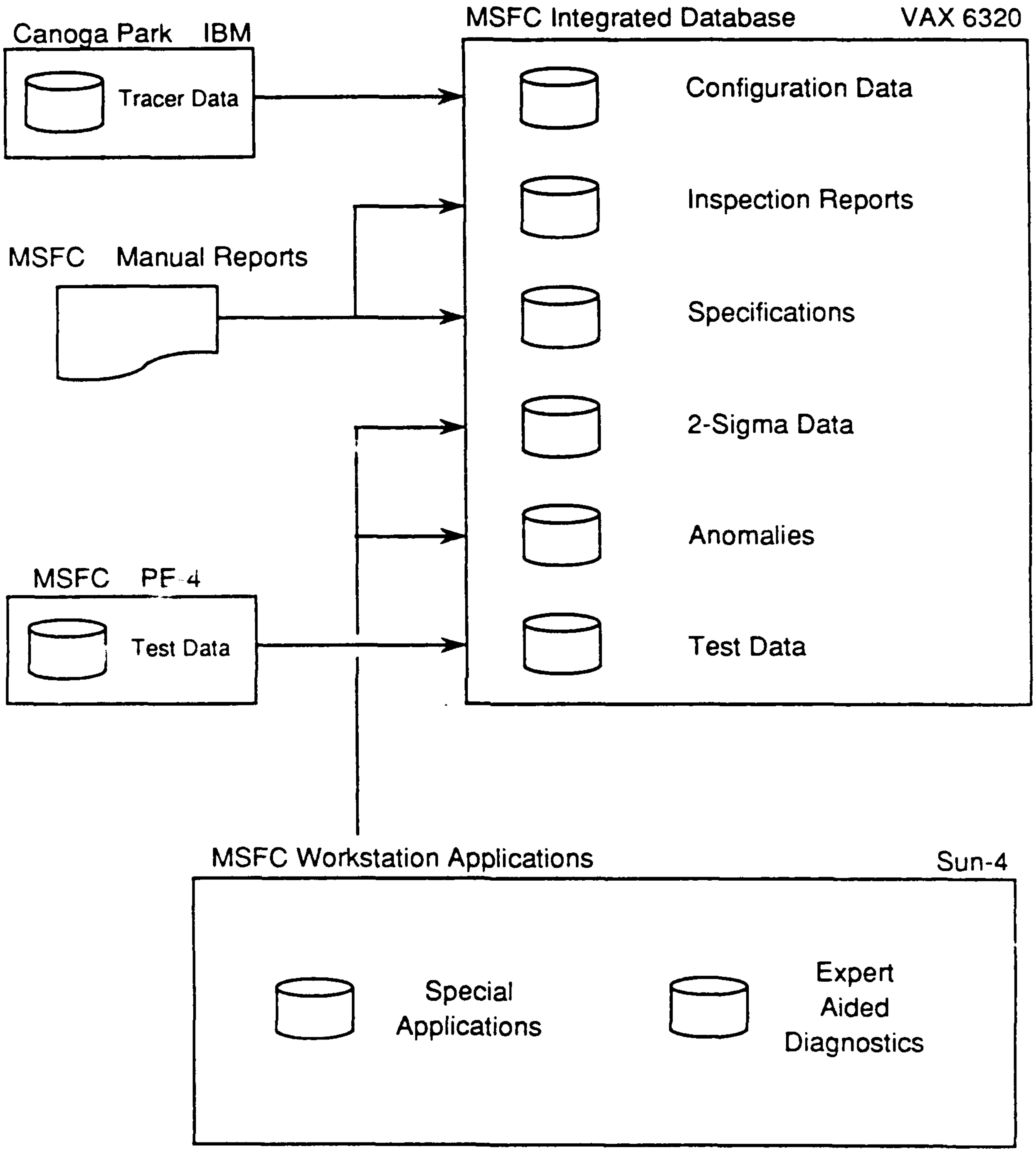

FIGURE 4-2 **The Integrated Database Consolidates Diagnostic Information from Various Sources**

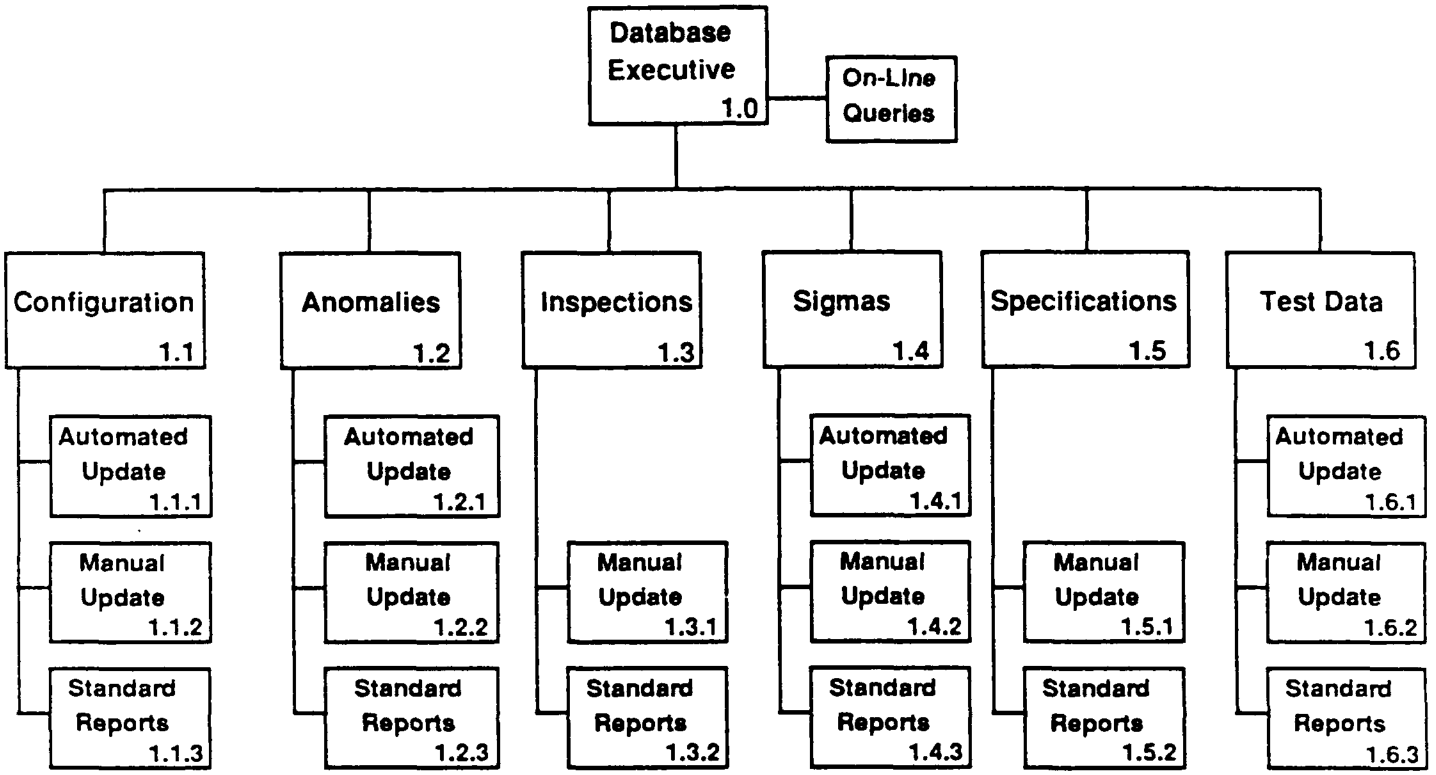

FIGURE 4-3 Summary of Database Applications

The integrated database will be hosted on a VAX 6320 at MSFC under the Ingres database management system (dBMS). Maintenance of the data in the integrated database will be accomplished by a combination of Ingres capabilities and procedural programs. Manual updates to the contents of the data files will be possible through Ingres. Automated updates of the configuration, anomaly, sigma and test data files will be accomplished via procedural programs working in conjunction with Ingres.

Standard reports on the contents of individual data files in the integrated database will be provided under Ingres. On-line reports which involve joins of data from various data categories and files will be provided through Ingres in response to user-defined queries.

Figure 4-3 shows the applications which will be provided to maintain and report the contents of the integrated database.

The physical output of the integrated database will be reports which show the current contents of the database files. These are the standard reports listed in Figure 4-2. An example of a standard report is shown in Figure 4-4.

DATABASE REPORT FOR FILE: Sigma'Values

DATE:31 Aug 1990

Operating Phase	Power Level	PID Number	Sensor Description	Mean Value	One Sigma Value
Mainstage	100	163	MCC Pc	3006.25	1.31
Maintstage	100	203	LPFP DS P	224.80	12.92
Mainstage	100	225	LPFP DS T	42.62	0.48
Mainstage	100	152	HPFP DS P	5878.55	36.03
Mainstage	100	231	HPFT T A	1662.71	59.41
Mainstage	100	232	HPFT T B	1678.84	45.95
Mainstage	100	261	HPFTP SPD	34389.38	238.97
Mainstage	100	209	LPOP DS P	352.40	19.10
Mainstage	100	190	HPOP DS P	3883.72	23.92
•	•	•	•	•	
•	•	•	•	•	
•	•	•	•	•	

FIGURE 4-4 Typical Report of Database Contents

4.2.2 Data Structures

Preliminary Ingres file structures were developed for each of the major data categories. These file structures are shown in Table 4-1, and include the field name, data type and field length. Four data types were used: character, integer, floating point, and note. The length of character, integer, and floating point fields are shown in Table 4-1. The note data type is a field of dynamically variable length which can hold text or graphical information.

DATABASE: CONFIG

File: Hardware

TEST'NO, I, 6
TEST'DATE, C, 6
ENGINE, C, 6
HPOP'UN, C, 8
HPFP'UN, C, 8
LPOP'UN, C, 8
LPFP'UN, C, 8
HPOP'SN, C, 8
HPFP'SN, C, 8
LPOP'SN, C, 8
LPFP'SN, C, 8
PWR'HEAD, C, 6
MAIN'INJ, C, 6
MCC, C, 6
NOZZLE, C, 6
CNTRLR, C, 6
HPOP'IMP, C, 10

File: Test'Profile

TEST'NO, I, 6
START'TIME, F, 6
END'TIME, F, 6
POWER'LEVEL, F, 6

DATABASE: ANOMALY

File: Anomaly'List

TEST'NO, I, 6
ANOMALY'TIME, F, 6
ANOMALY'COMP'NAME, C, 6
RID'NO, I, 6
MR'NO, I, 6
UCR'NO, I, 6
ANOMALY'DESCRIP, NOTE
ANOMALY'SIGNATURE, NOTE
ANOMALY'RESPONSE, NOTE

TABLE 4-1 File Structures

```
DATABASE: INSPECTIONS

   File: Hpop'I'Rpt

        ENGINE,I,4
        TEST'NO,I,6
        INSP'DATE,I,6
        ENGINEER,C,35                 'inspection engineer
        TT'BRK,F,6                    'breakaway torque
        TT'PRM,F,6                    'running torque
        TT'COM,NOTE                           'torque comments
        SM'OVERALL,NOTE               'turbine inlet sheetmetal appearance
        SM'STRUT'LEAD,NOTE
        SM'STRUT'SIDE,NOTE
        SM'STRUT'TRAIL,NOTE
        SM'STRUT'WELDS,NOTE
        S1'NOZ'OVERALL,NOTE
        S1'NOZ'IO'SHROUD,NOTE
        S1'NOZ'VANE'LEAD,NOTE
        S1'NOZ'VANE'AIR,NOTE
        S1'NOZ'VANE'TRAIL,NOTE
        S1'TURB'BLD'LEAD,NOTE
        S1'TURB'BLD'AIR,NOTE
        S1'TURB'BLD'I'SHROUD,NOTE
        S1'TURB'BLD'O'SHROUD,NOTE
        BRG'3'CAGE,NOTE
        BRG'3'RACE,NOTE
        BRG'3'BALLS,NOTE
        BRG'3'PHOTOS,C,1
        MAIN'IMP,NOTE
        TURN'VANE,NOTE
        PBP'INLET,NOTE
        PBP'IMP'BOLT'LOCK,NOTE
        PRI'LOX'SL'LEAK'CHK'DATE,C,6
        PRI'LOX'SL'LEAK'RATE,F,6
        PRI'TURB'SL'LEAK'CHK'DATE,C,6
        PRI'TURB'SL'LEAK'RATE,F,6
        TEST'PLATE'THICKNESS,F,6
        BASE'MEASURE,F,6
        MEAS'ROTOR'END'P1,F,6
        MEAS'ROTOR'END'P2,F,6
        MEAS'ROTOR'END'P3,F,6
        MEAS'ROTOR'END'P4,F,6
        S2'TURB'BLD,NOTE
        G2'SL,NOTE
        G3'SL,NOTE
        ER,NOTE                                          ' eccentric rings
```

TABLE 4-1 File Structures (Cont'd)

```
File: Lpop'I'Rpt

     ENGINE,I,4
     TEST'NO,I,6
     INSP'DATE,I,6
     ENGINEER,C,35                'inspection engineer
     TT'BRK,F,6
     TT'PRM,F,6
     TT'COM,NOTE


File: Hpfp'I'Rpt

     ENGINE,I,4
     TEST'NO,I,6
     INSP'DATE,I,6
     ENGINEER,C,35                'inspection engineer
     TT'BRK,F,6                   'breakaway torque
     TT'PRM,F,6                   'running torque
     TT'COM,NOTE                       'torque comments
     SHAFT'DIM,F,6
     SHAFT'TVL,F,6
     B'MARK'ALIGN,NOTE
     SM'OVERALL,NOTE              'turbine inlet sheetmetal appearance
     SM'STRUT'LEAD,NOTE
     SM'STRUT'SIDE,NOTE
     SM'STRUT'TRAIL,NOTE
     SM'STRUT'WELDS,NOTE
     KAISER'NUT,NOTE
     THERM'SHLD,NOTE
     S1'NOZ'OVERALL,NOTE
     S1'NOZ'IO'SHROUD,NOTE
     S1'NOZ'VANE'LEAD,NOTE
     S1'NOZ'VANE'AIR,NOTE
     S1'NOZ'VANE'TRAIL,NOTE
     TURB'TIP'SL'OVERALL,NOTE
     TURB'TIP'SL'FILLER,NOTE
     TURB'TIP'SL'JNT,NOTE
     S1'TURB'BLD'LEAD,NOTE
     S1'TURB'BLD'AIR,NOTE
     S1'TURB'BLD'PLAT,NOTE
     S1'TURB'BLD'TRAIL,NOTE
     S1'TURB'BLD'DAMP,NOTE
     PLATFORM'SL,NOTE
     TURB'DSCH'SM'OVERALL,NOTE
     TURB'DSCH'TA'MANI,NOTE
     TURB'DSCH'O'BELLOWS,NOTE
     S2'TURB'BLD'TURB'DSCH,NOTE
     S2'TURB'BLD'DAMP,NOTE
     BAL'PIST'GAP,F,6
     SHIM'THICKNESS,F,6
     BRG'INLET'COOL'HOLES,NOTE
     BRG'DSCH'COOL'HOLES,NOTE
     PUMP'END'TURB'END'SL,NOTE
     G6'FLANGE,NOTE
     S1'TIP'SL'RETAIN'LUG,NOTE
     S2'TIP'SL,NOTE
```

TABLE 4-1 File Structures (Cont'd)

```
File: Lpfp'I'Rpt

ENGINE,I,4
TEST'NO,I,6
INSP'DATE,I,6
ENGINEER,C,35                  'inspection engineer
TT'BRK,F,6                     'breakaway torque
TT'PRM,F,6                     'running torque
TT'COM,NOTE                            'torque comments


File: Cdev'I'Rpt

ENGINE,I,4
TEST'NO,I,6
INSP'DATE,I,6
ENGINEER,C,35                  'inspection engineer
SPARK'1,NOTE
SPARK'2,NOTE
ASI'OX'ORI,NOTE
ASI'FU'ORI'NOTE
ASI'CHAMBER,NOTE
INJ'REMARKS,NOTE
MCC'ROUGH'BEFORE'TYP,C,15
MCC'ROUGH'BEFORE'MAX,C,15
MCC'ROUGH'BEFORE'3UP,C,15
MCC'ROUGH'BEFORE'4DN,C,15
MCC'REMARKS,NOTE
NOZ'REMARKS,NOTE
TPS'REMARKS,NOTE
FPB'BAFFLE'1,NOTE
FPB,BAFFLE'2,NOTE
FPB,BAFFLE'3,NOTE
FPB'SPARK'1,NOTE
FPB'SPARK'2,NOTE
FPB'OX'ORI,NOTE
FPB'FU'ORI,NOTE
FPB'CC,NOTE
FPB'REMARKS,NOTE
OPB'BAFFLE'1,NOTE
OPB,BAFFLE'2,NOTE
OPB,BAFFLE'3,NOTE
OPB'SPARK'1,NOTE
OPB'SPARK'2,NOTE
OPB'OX'ORI,NOTE
OPB'FU'ORI,NOTE
OPB'CC,NOTE
OPB'REMARKS,NOTE
```

TABLE 4-1 File Structures (Cont'd)

DATABASE: SIGMAS

Datafile: Sigma'Tests

TEST'NO, I, 6
ENGINE'PHASE,C,1
POWER'LEVEL, F, 6
PID'NO,I,6
MEAN'TEST'VALUE,F,6

Datafile: Sigma'Values

ENGINE'PHASE, C, 1
POWER'LEVEL, F, 6
PID'NO, I, 6
MEAN'VALUE, F, 6
ONE'SIGMA'VALUE, F, 6

DATABASE: SPECIFICATIONS

Datafile: Specifications

SPEC'TYPE,C,1	'A (Acceptance), I (ICD), G (Green Run)
PID'NO,I,6	
ENGINE'PHASE,C,1	'P(Pre-start), S(Start), M(Mainstage), D(Shutdown)
START'TIME,F,6	
END'TIME,F,6	
HIGH'LIMIT,F,6	
LOW'LIMIT,F,6	
TREND'LIMIT,F,6	'In engineering units/sec
VIOLATION'DESCRIPTION,NOTE	

TABLE 4-1 File Structures (Cont'd)

4.2.3 Database HIPO Analysis

As discussed in Section 4.2.1, applications are required to maintain and report on the contents of the integrated database. A summary of the required applications was shown in Figure 4-3. This section defines each of these applications through the use of a Hierarchical Input Process Output (HIPO) analysis. Shown in these HIPO analyses are the input into each application, a description of the processing done within the application, and the output of each application.

4.2.3.1 Configuration Data

4.2.3.1.1 Automated Updates of Configuration Data

4.2.3.1.1.1 Input

A. Configuration and test'profile datafiles.

B. User request to automatically update the Configuration database for specified test number(s).

C. Tracer hardware configuration files.

D. SSME Test Data for selected test number(s).

4.2.3.1.1.2 Process

A. Open communication link to RKDN Tracer Program.

B. Retrieve test number, date, and LRU identifiers matching user request. Format data.

C. Transfer update file to VAX.

D. For each record in update file,
Search for match in configuration file. (Key: test'no).
If match
    THEN Replace existing record.
    ELSE Append new record

E. Open communication link to PE-4.

F. Locate SSME test data for the specified test(s).

G. For each measurement point in test data file(s)
  (1) Calculate power level, rounded to nearest percent
  (2) Test against previous power level calculation
      If equal
          THEN do nothing
          ELSE
              i. add end time to open test'profile record
              ii. construct new record with start time for test'profile

H. Load resulting file into Test'Profile datafile.
   (1) Append new records (key: test'no)
   (2) Replace existing records for key match

4.2.3.1.1.3 Output

Automatically updated Configuration and test'profile datafiles for specified test number(s).

4.2.3.1.2 Manual Updates of Configuration Data

4.2.3.1.2.1 Input

A. Configuration and test'profile data files.

B. User request to manually update data

4.2.3.1.2.2 Process

A. User enters edit mode.

B. Records appear from configuration and test'profile data files indexed by test'no. User has keyboard control to
   Add -- new records
   Delete -- a character, or record
   Change -- contents of any field
   Save -- work to date
   Abort -- edits this session

C. Upon exit of edit mode, edited records are saved.

D. Reindex edited data files.

4.2.3.1.2.3 Output

Manually edited configuration and test'profile datafiles.

4.2.3.1.3 Standard Reports of Configuration

4.2.3.1.3.1 Input

A. Configuration and test'profile data files.

B. User request for standard report.

C. User designation of report sort order and search condition(s).

4.2.3.1.3.2 Process

A. Open configuration and test'profile data files.

B. Construct report based on specified sort order and search condition.

C. Display results on screen or send to printer as requested.

4.2.3.1.3.3 Output

Screen display or printed report shown in Figure 4-4.

4.2.3.2 Anomalies Data

4.2.3.2.1 Automated Updates of Anomalies Data

4.2.3.2.1.1 Input

A. Anomaly datafile.

B. Identified test anomaly from Expert-Aided Diagnostics Applications.

C. User permission to record identified anomaly.

4.2.3.2.1.2 Process

A. Open Anomaly Datafile.

B. Add new record with test'no, anomaly'time, anomaly'comp'name, anomaly description (text), and anomaly'signature (text and/or graphic(s)) as provided by expert aided diagnostic application.

C. Note no search to prevent duplicate entries for same anomaly.

D. Permit user to edit new data provided by expert aided diagnostic application.

E. Permit user to add rid'no, mr'no, and ucr'no.

4.2.3.2.1.3 Output

Anomaly datafile with added anomaly record. Possibly a new anomaly signature.

4.2.3.2.2 Manual Updates of Anomalies Data

4.2.3.2.2.1 Input

A. Anomaly data file.

B. User request to manually update data

4.2.3.2.2.2 Process

A. User enters edit mode.

B. Records appear from Anomaly data files indexed by test'no. User has keyboard control to
Add -- new records
Delete -- a character, or record
Change -- contents of any field
Save -- work to date
Abort -- edits this session

C. Upon exit of edit mode, edited records are saved.

D. Reindex edited data files.

4.2.3.2.2.3 Output

Manually edited Anomaly datafiles.

4.2.3.2.3 Standard Reports of Anomalies Data

4.2.3.2.3.1 Input

A. Anomaly data file.

B. User request for standard report.

C. User designation of report sort order and search condition(s).

4.2.3.2.3.2 Process

A. Open Anomaly data file.

B. Construct report based on specified sort order and search condition.

C. Display results on screen or send to printer as requested.

4.2.3.2.3.3 Output

Screen display or printed report.

4.2.3.3 Inspections/Data

4.2.3.3.1 Manual Updates of Inspection Data

4.2.3.3.1.1 Input

A. Inspection data files.

B. User request to manually update data

4.2.3.3.1.2 Process

A. User enters edit mode.

B. Records appear from Inspection data files indexed by test'no. User has keyboard control to
Add -- new records
Delete -- a character, or record
Change -- contents of any field
Save -- work to date
Abort -- edits this session

C. Upon exit of edit mode, edited records are saved.

D. Reindex edited data files.

4.2.3.3.1.3 Output

Manually edited Inspection datafiles.

4.2.3.3.2 Standard Reports of Inspection Data

4.2.3.3.2.1 Input

A. Inspection data files.

B. User request for standard report.

C. User designation of report sort order and search condition(s).

4.2.3.3.2.2 Process

A. Open Inspection data files.

B. Construct report based on specified sort order and search condition.

C. Display results on screen or send to printer as requested.

4.2.3.3.2.3 Output

Screen display or printed report.

4.2.3.4 Sigma Data

4.2.3.4.1 Automated Updates of Sigma Data

4.2.3.4.1.1 Input

A. Sigma data files.

B. Temporary update file of validated SSME hot fire data as analyzed by special application module sigma.

C. User permission to update sigma datafiles with data from this test.

4.2.3.4.1.2 Process

A. Open sigma data files and temporary update file produced by special application sigma.

B. For each record in temporary update file.

C. Search for match in sigma'test file (key: test'no + engine'phase + power'level + pid'no)
   If match
   THEN display record exists message. Allow user to overwrite.
   ELSE update sigma data files with info from new test.

4.2.3.4.1.3 Output

Automated update of sigma data files.

4.2.3.4.2 Manual Updates of Sigma Data

4.2.3.4.2.1 Input

A. Sigma data files.

B. User request to manually update data.

4.2.3.4.2.2 Process

A. User enters edit mode.

B. Records appear from Sigma data files indexed by test'no. User has keyboard control to
Add -- new records
Delete -- a character, or record
Change -- contents of any field
Save -- work to date
Abort -- edits this session

C. Upon exit of edit mode, edited records are saved.

D. Reindex edited data files.

4.2.3.4.2.3 Output

Manually edited Sigma datafiles.

4.2.3.4.3 Standard Reports of Sigma Data

4.2.3.4.3.1 Input

A. Sigma data files.

B. User request for standard report.

C. User designation of report sort order and search condition(s).

4.2.3.4.3.2 Process

A. Open Sigma data files.

B. Construct report based on specified sort order and search condition.

C. Display results on screen or send to printer as requested.

4.2.3.4.3.3 Output

Screen display or printed report.

4.2.3.5 Specifications Data

4.2.3.5.1 Manual Updates of Specifications Data

4.2.3.5.1.1 Input

A. Specification data files.

B. User request to manually update data

4.2.3.5.1.2 Process

A. User enters edit mode.

B. Records appear from Specification data files indexed by test'no. User has keyboard control to
   Add -- new records
   Delete -- a character, or record
   Change -- contents of any field
   Save -- work to date
   Abort -- edits this session

C. Upon exit of edit mode, edited records are saved.

D. Reindex edited data files.

4.2.3.5.1.3 Output

Manually edited Specification datafiles.

4.2.3.5.2 Standard Reports of Specifications Data

4.2.3.5.2.1 Input

A. Specification data files.

B. User request for standard report.

C. User designation of report sort order and search condition(s).

4.2.3.5.2.2 Process

A. Open Specification data files.

B. Construct report based on specified sort order and search condition.

C. Display results on screen or send to printer as requested.

4.2.3.5.2.3 Output

Screen display or printed report.

4.2.3.6 Test Data

4.2.3.6.1 Automated Updates of Test Data

4.2.3.6.1.1 Input

A. Full SSME CADS or Facility Test data on Perkin Elmer-4.

B. Test number, start and end times, and sampling rate provided by user.

4.2.3.6.1.2 Process

A. Open communications link to VAX.

B. Lookup test number on VAX to see if a copy of data already exists for the requested test.

C. If file exists on VAX
THEN display existing header record information to user.
Ask user if they want new data.
IF user wants new data,
THEN proceed to next step.
ELSE end automated update without new data transfer

D. Open communications link to PE-4.

E. Lookup test number on PE-4 on-line disk storage.

F. IF file exists on PE-4
THEN proceed with data transfer per user request
ELSE display not on line message to user. Allow tape load request

4.2.3.6.1.3 Output

SSME Data transferred from PE-4 to VAX at user requested sampling rate and start and stop times. Data storage format will be SSME Data Format D (see Table 4-2).

Rec#	Sec#	Record Description		Data Type/Size	
1	0	File Formatting Information		CMAR*252	
2	1	Comment Record 1		CHAR*252	
3	2	Comment Record 2		CHAR*252	
4	3	Comment Record 3		CHAR*252	
5	4	Comment Record 4		CHAR*252	
6	5	Comment Record 5		CHAR*252	
7	6	File Map	(Time words)	REAL	TW (315)
8	11	File Map	(Disk Records)	INTEGER	DR (315)
9	16	Zero Shift Data Averages		REAL	ZS (?)
10	*	Staleness Factors		REAL	SF (?)
11	*	Header #1	(Test Title)	CHAR*?	H1
12	*	Header #2	(Test File Information)	REAL	H2 (63)
13	*	Header #3	(Measurement IDs)	CHAR*?	H3 (?)
14	*	Header #4	(Engineering units)	CHAR*?	H4(?)
15	*	Header #5	(Measurement Titles)	CHAR*?	H5(?)

TABLE 4-2 SSME Data Format D

Rec#	Sec#	Record Description	Data Type/Size
16	*	\ Up to 15 Optional User Defined \ Header Records > / (number of records specified / in header record 2)	Data may be of any type and size.
?	*	Start of Test Data	
1		\ \ > Test Data Records / /	REAL TD (?)
EOF		End of Test Data	

* Sector addresses for these records are supplied by Header record number 2.

GENERAL RECORD DESCRIPTIONS FOR FORMAT D

1) Record #1 contains information about the format of the file. The record is in FORTRAN type CHARACTER*252. For the "D" format the first 17 characters of this record are as follows:
"DATA FORMAT=D XXX"

2) XXX is a three digit integer number which holds the file sector number of header record 2. This allows programs to quickly bypass comment and filemap records if so desired. Character positions 18 through 252 may be used as desired. Normally, the name of the file generating program and it's version number are specified enclosed in asterisks (*). For example, if a program called "SCALETTB" were to produce a format "D" file, the first record might read:
"DATA FORMAT=D 116 *SCALETTB v1.31*"

3) The program name including the asterisks should not be over 20 characters long because utility routines exist which make this field available to user programs as a CHARACTER*20 entity. The program name field may appear anywhere in the record except in the first 17 characters.

4) Records #2 through #6 is free file space not currently used. Any file creation program may use this area to hold comments, program specific data, ect. Each record is of type CHARACTER*252.

5) Records #7 and #8 contain a map of the file's data area. Record #7 is 315 REAL words and record #8 is 315 INTEGER words. The file generating program does not compute the data for these two records; instead, programs write two dummy records as place holders. After the complete file is written, a program utility "FILMAP" is used to scan the test data portion of the file and overwrite the two dummy records with file mapping information. The methods used to map a file are detailed in document "SSME SINGLE ENGINE TEST DATA ACCESS" number IL 86-129-289 in section 3.7 "DATACC.LIB File Mapping Method". Programs which later read data may use routines designed to use the file map to directly access any record in the file's test data area.

6) Record #9 contains zero shift averages as REAL words. The zero shift averages are produced by averaging the test data over the -2 to -1 second time period before engine start. The resulting averages may then be used by user programs to compute a bias to apply to certain test parameters in order to correct calibration. File generating programs do not not need to compute the data for this record; instead, programs write one dummy record of zero values (0.0) as a place holder. After the complete file is written, a program utility "FILEMAP" is used to compute the zero shift values and overwrites this record. If the zero shift values can not be computed, the zero values are left in place causing programs which use zero shifts to apply no bias.

TABLE 4-2 SSME Data Format D (Cont'd)

7) Record #10 contains staleness factors for each measurement listed in record #13. The staleness factor is the time adjustment to be added to time to compute the exact time at which each individual measurement value was recorded. Any file creation program should compute these factors and insert this record. If the staleness factors are not known or not computable, a record of zero values (0.0) should be written. This will cause user programs which apply staleness to ignore any time adjustment.

8) Record #11 contains the first of five standard header records. Header #1 constitutes the test title in FORTRAN type CHARACTER and may be of any length. Word number 22 in header #2 points to the sector of header #1 and word 23 indicates it's length. A common CADS file might have "SSME CONTROLLER DATA FOR TEST 9010460" written in this record.

9) Record #12 contains header #2. In this record there are 63 floating point words which give information about the test file itself. These 63 words are described by the following:

WORD	DESCRIPTION
1	Spare (normally 0.0)
2	Spare (normally 0.0)
3	Number of PIDS contained in this file
4	Spare (normally 0.0)
5	Spare (normally 0.0)
6	Number of PIDS plus one plus time word
7	Spare (normally 1.0)
8	*Test Stand Number (901=A1, 902=A2, 750=A3, 904=BI)
9	*Test Run Number
10	Year and Day (ie. 5070. for 85:070)
11	Spare (normally 0.0)
12	Spare (normally 0.0)
13	Engine Cutoff Time in Seconds
14	Sector Address of the Start of Test Data Area
15-20	Calender Time of Engine Start in the form Years,Days, Hours, Mins, Secs, Msecs
21	Engine Serial Number
22	Sector Address of Header #1
23	Character Length of Header #1
24	Sector Address of Header #2
25	Sector Address of Header #3
26	Character Length of Header #3
27	Sector Address of Header #4
28	Character Length of Header #4
29	Sector Address of Header #5
30	Character Length of Header #5
31	Sector Address of Zero Shift Averages
32	Sector Address of Staleness Factors
33	Number of User Defined Header Records (0 - 15)
34	Sector Address of 1st User Header Record
35	Entity Length of 1st User Header Record
	•
	•
	•
62	Sector Address of 15th User Header Record
63	Entity Length of 15th User Header Record

TABLE 4-2 SSME Data Format D (Cont'd)

* When this file format is used to contain STS flight data, a "single-engine-like" test run number must be synthesized for words 8 and 9. The method used is as follows: Word 8, Characters 1-3 = STS Mission Number or MPTA Test Number Word 9, Character 1 = Cycle Number for MPTA or STS Scrub/Abort Word 9, Character 2 = Event Site (0-KSC, 1-VAB, 2-NSTL) Word 9, Character 3 = Event Type (0-STS, 1-Scrub, 2-Abort, 3-FRF, 4-MPTA) Word 9, Character 4 = Engine Position (1-ME1, 2-ME2, 3-ME3)
10) Record #13 contains header #3. This record is a list of the measurement IDs available in the file. Each ID is of type CHARACTER and may of any length. Header #2, words 25 and 26, specify the sector address and string length of header #3 entities. The order in which the measurements are listed identifies the order in which all other header and data records are written. The PID number is usually in the first four characters. 11) Record #14 contains header #4. This record supplies the engineering unit of measure for each item in header #3. Each unit is of type CHARACTER and may be of any length. Header #2, words 27 and 28, specify the sector address and string length of header #4 entities. 12) Record #15 contains header #5. This record supplies the title of each item in header #3. Each title is of type CHARACTER and may be of any length. Header #2, words 29 and 30, specify the sector address and string length of header #5 entities. 13) The next ID records may be used by users to add special header records to the file. The type and length of the entities are up to the user to define. Since these records are optional, no user defined records may be defined for some files. Word 33 of header #2 specifies the number of records defined. 14) All remaining records in the file are test data records. Each data record constitutes a floating point data sample in time for all PIDs listed in header #3. Word 14 of header #2 specifies the sector address of the first data record.

TABLE 4-2 SSME Data Format D (Cont'd)

4.2.3.6.2 Manual Updates of Test Data

4.2.3.6.2.1 Input

A. Test Data data files.

B. User request to manually update data

4.2.3.6.2.2 Process

A. User enters edit mode.

B. Records appear from Test Data data files indexed by test'no. User has keyboard control to
  Add -- new records
  Delete -- a character, or record
  Change -- contents of any field
  Save -- work to date
  Abort -- edits this session

C. Upon exit of edit mode, edited records are saved.

D. Reindex edited data files.

4.2.3.6.2.3 Output

Manually edited Test Data datafiles.

4.2.3.6.3 Standard Reports of Test Data

4.2.3.6.3.1 Input

A. Test Data data files.

B. User request for standard report.

C. User designation of report sort order and search condition(s).

4.2.3.6.3.2 Process

A. Open Test Data data files.

B. Construct report based on specified sort order and search condition.

C. Display results on screen or send to printer as requested.

4.2.3.6.3.3 Output

Screen display or printed report.

4.3 COMPUTER AIDED ENGINEERING

4.3.1 Applications Programs

Two applications are required to provide the necessary computer aided engineering (CAE) capability to the workstation (see Figure 4-5). An interface application will retrieve and format data from the integrated databases and a commercial CAE package will provide the graphical data analysis functions for the CAE environment.

The data interface application provides access to SSME test and flight data as a user defined set of parameter retrievals from the Ingres database. The interface application will format the data for the analysis program as required.

A commercial CAE application will be selected to provide the CAE environment. Data will be supplied to the program from the integrated database by the data interface application. Batch programs will generate pre-defined plots for each test segment. Output will be available on screen in real time, or as post-script output suitable for a laser printer. The user will be able to actively manipulate, analyze, and redisplay the test data sets using features of the commercial package.

The analysis process for each SSME test or flight will begin when the parametric data has been transferred to the file server. Plot data set definitions and report formats developed by individual analysts will be input to this process.

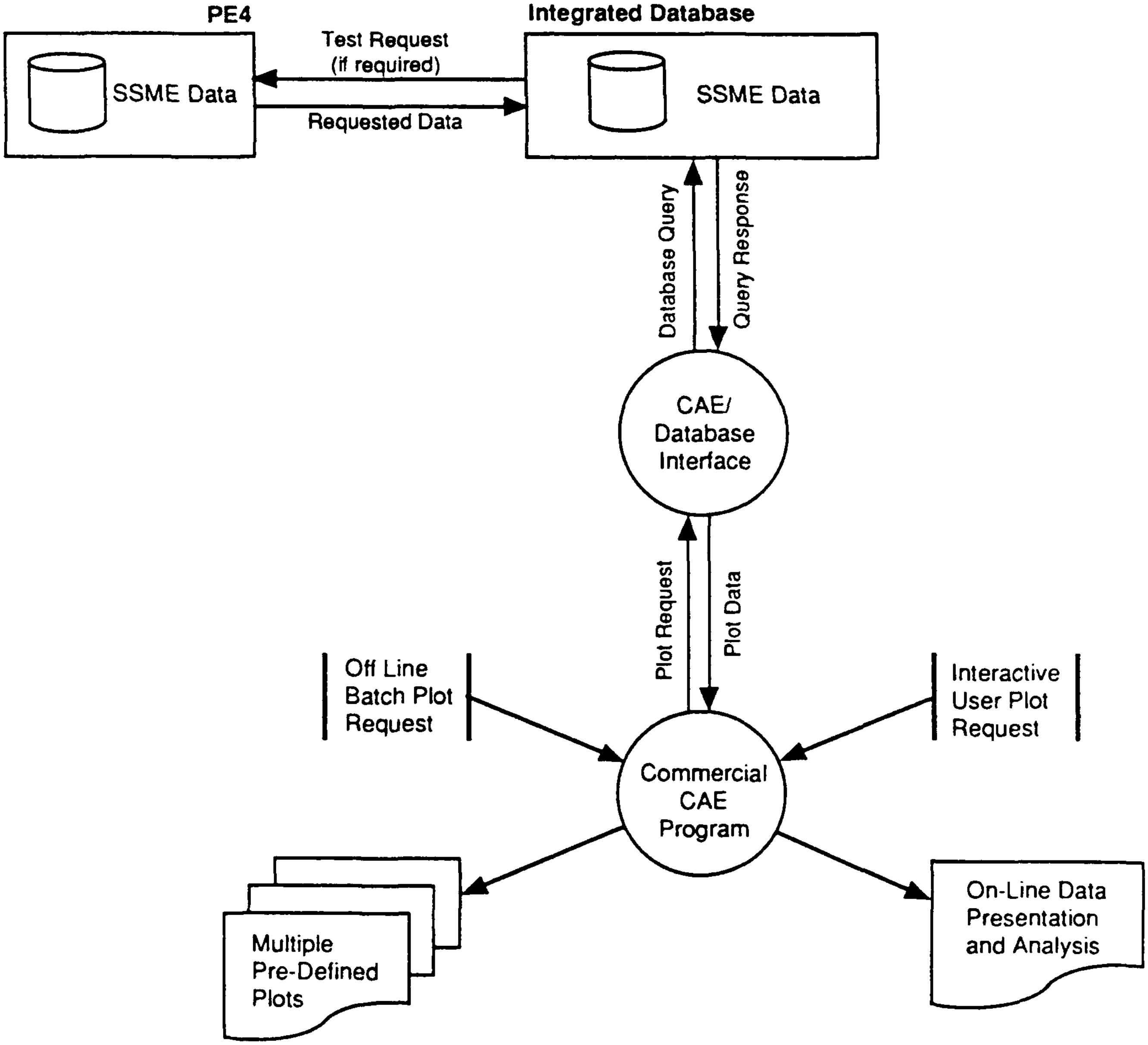

FIGURE 4-5 CAE Functionality Will Be Provided by a Commercial CAE Program in Concert with an Automated Interface to the Integrated Database

The CAE application will be menu driven. The analyst can select pre-defined plot packages for on line examination or hard copy print. Data will include test parameters, pre-defined text, a textual data, curve fits, statistics, etc. defined for the plot format. The analyst can flexibly manipulate the plot display using the mouse to zoom and enhance scaling accuracy, identify numeric values of specific plotted points under mouse control, and edit data including cut/paste functions. Multiple windows can be opened simultaneously to compare data on different plots.

Plot information may be printed at any time to the laser printers. Additionally, a full set of "canned" plots can be created in hard copy using a batch operation.

Output formats will include a wide variety of 2D/3D formats for data display. Plot definitions will allow layouts to be pre-defined with plots produced when the program is executed. Plots which have been created can be stored and accessed for later comparison as examples of nominal or anomalous behavior.

4.3.2 Evaluation of CAE packages

Over forty commercial data analysis, graphics, and statistics packages were evaluated (see Figure 4-6) to determine their potential suitability for this application. The following required feature provided the basis for evaluation:

a. Compatible with a SUN workstation including multi-window operation;

b. Flexible data input formats including, if possible, easily implemented bridges to the Ingres databases and sufficiently large data table size;

c. Flexible 2D/3D full color graphics including a wide variety of plot formats;

d. Post-script output device support;

e. Batch and macro operation available to provide standard sets of plot reports for each test segment;

f. Application language for implementation of mathematical manipulation, statistics, and signal processing functions;

g. Fully integrated mouse support including autozoom, data cut, paste and editing and data value examination under mouse control;

h. Data management capabilities within the analysis program itself to allow storage and retrieval of plot images without regeneration of the parametric data; and

i. Efficient operation and suitable response time on selected processor platform.

CAN	PROGRAM NAME	VENDOR	TYPE				DATA MANAGE-MENT	APPLI-CATION LANGUAGE	INPUT FILE FORMAT	APPROX PRICE	COMMENTS
			PLOT	MATH	STAT	OTHER					
*	TECPLOT	Amtec	X				NO	NO	ASCII	$ 1700	Full featured package with data manipulation, multiple zoom, 2D/3D, point value examination, extract, batch/macro, style sheets, Post-Script output, flexible text
	AUTOBOX	Automatic Forecasting		X		X	YES	NO	ASCII	$ 1195	Forecasting program used to develop mathematical models from data and to forecast future behavior based upon trends. Expert interface, mouse driven, data management system, and graphics output. Very special purpose application.
*	RS/1	BBN Software	X	X	X	X	YES	YES	Many	$ 4000 - $ 6000	Full feature data analysis package including graphics, statistics, modeling report generation, application language, and data management system. Package also permits development of full applications including menus, windows, etc. Unlimited data table sizes, interfaces to multiple file formats and manages all data types. Provides multiuser access to databases. Mature package.
	SpeedGraphics	Bio-cybernetics					NO	NO	Many	$ 50	Subroutine library for the Sun workstation to be included in existing FORTRAN. C or PASDCAL programs. Efficient operation.

FIGURE 4-6 Summary of Commercial Packages Investigated

CAN	PROGRAM NAME	VENDOR	TYPE				DATA MANAGE-MENT	APPLI-CATION LANGUAGE	INPUT FILE FORMAT	APPROX PRICE	COMMENTS
			PLOT	MATH	STAT	OTHER					
	SIMPLEPLOT	Bradford University Services	X	X			NO	NO		$ 1000	FORTRAN 77 library of plot routines to be incorporated into existing programs. Wide variety of 2D/3D, contours, graph types, shading, labeling and color effects. Output is device independent.
	C-PLOT	Certified Scientific Software	X	X			NO	YES	ASCII or User Functions	$ 1000	Package for 2D graphics. Batch file operation for reports. Laser printer, plotter output. Statistics limited to curve fitting. Data input from files or user functions.
	COSMIC	NASA					NO	NO		Varied	NASA catalog of public domain applications. None seemed relevant to workstation CAE.
	CUFFS-88	CUFFS Planning									*No response.*
	IFPS/Plus	EXECUCOM					NO	NO		N/A	Decision support system for financial planning.
	Autograph	FICOR	X				NO	NO	ASCII		Business graphics package with simple graph types and easy user interface.
	GENPLOT	Frazer-Nash Consultancy	X				NO	NO	Several	$ 1700	Line, bar and pie chart program. Minimal editing and text capabilities. Zoom in and out. Multiple view ports and multiple plots per port.
	Zetz!	H2 0, Inc.									*No response.*
	Harwell Subroutine Library	Harwell Laboratory		X			NO	NO	Program	$ 1600/yr	Library of 350 numerical analysis and modelling routines offered by UK Atomic Energy Authority.
	ITR Nurbs Library	Industrial Technics									Library of C language routines for graphics, modelling and mathematics.

FIGURE 4-6 Summary of Commercial Packages Investigated (Cont'd)

CAN	PROGRAM NAME	VENDOR	TYPE				DATA MANAGE-MENT	APPLI-CATION LANGUAGE	INPUT FILE FORMAT	APPROX PRICE	COMMENTS
			PLOT	MATH	STAT	OTHER					
	MATRIXx/WS Plus	Integrated Systems	X	X		X	NO	YES	Several	$ 4495	Control design and system simulation package. Provides 2D/3D plotting capabilities, matrix manipulation and signal processing in CAE environment.
	GINO LINDO LINGO	Lindo Systems		X			NO	NO	None	$ 3000	Optimizer package for linear and integer programming.
	Mathstation	Mathsoft	X	X			NO	YES	Many	$ 2450	Mathematical environment for analysis and plotting. High level language used for equations and calculations. Line and 2D/3D graphics and interfaces to other plotting packages. Based on FORTRAN program.
*	MATLAB	Mathworks Inc.	X	X	X	X	NO	YES	Many	$ 6500 - $ 20000	A CAE environment implementing a C-language based mathematics workstation with 2D/3D graphics. Integrated into the SUN workstation under UNIX, it uses windows for editing, commands and display. Procedure files are used for calculation and standard graph generation. Interfaces to multiple file types are incorporated into language. Data size is unlimited.
*	TempleGraph	Mihalisin Associates	X	X	X		NO	YES	ASCII	$ 1290	High performance graphics program incorporating data analysis, statistics, curve fitting and calculus. Program has many flexible editing, cutting, rotation, zoom, scaling, etc. functions. Program uses mouse extensively and has report format storage.

FIGURE 4-6 Summary of Commercial Packages Investigated (Cont'd)

CAN	PROGRAM NAME	VENDOR	TYPE				DATA MANAGE -MENT	APPLI-CATION LANGUAGE	INPUT FILE FORMAT	APPROX PRICE	COMMENTS
			PLOT	MATH	STAT	OTHER					
*	TECHBASE	MINEsoft Ltd.	X	X	X	X	YES	YES	ASCII and User Defined	$ 13070	TECHBASE is a data analysis, graphics and modelling system incorporating a database management system to facilitate handling large data sets. Functions include complete 2D/3D graphics, curve-fitting statistics, and full data handling, editing, excerpting, etc. There is no limit to the database size.
	SPACE II	NIPPON System Gijutsu		X			NO	NO	None	$ 300	A library of numerical analysis routine in FORTRAN 77.
	Novacad	NOVACAD				X	YES	NO	None		CAD system with complete 2D/3D capabilities.
	MLP	Numerical Algorithms Group									*No response*
	OASYS	OASYS		X			NO	NO	None		Mathematical function library in C-language.
*	PV~WAVE	Precision Visuals	X	X	X		NO	YES	Many	TBQ	Full featured, high performance data analysis and plotting package. In addition to 2D/3D features, provides image processing, surface visualization and animation. Efficient operation and handling large data sets is advertised feature.
	Success Software	QualTech Systems									*No response.*
	MathAdvantage	Quantitative Tech Corporation		X			NO	NO	None	$ 4500	Math subroutine libraries for FORTAN and ADA programs including some graphics and plotting.

FIGURE 4-6 Summary of Commercial Packages Investigated (Cont'd)

CAN	PROGRAM NAME	VENDOR	TYPE				DATA MANAGE-MENT	APPLI-CATION LANGUAGE	INPUT FILE FORMAT	APPROX PRICE	COMMENTS
			PLOT	MATH	STAT	OTHER					
*	Base SAS SAS/GRAPH	SAS Institute	X	X			NO	YES	Many	$ 2790	Full feature data analysis and plot package.
	MGG Sciconic	Scicon Ltd.		X			NO	NO	Several	$ 21000	Optimization Program.
	CLAm	Scientific Computing Assoc.	X	X			YES	YES	Program	$ 4000	Interactive computing and visualization environment including image processing and animation. Allows access to C and FORTRAN routines from applications. Runs under X-Windows.
	DVERK	Scientific Computing Group									*No response.*
	Fractals Artist Toolkit	Small Systems									*No response.*
	SORITEC	Sorites Group, Inc.									*No response.*
	Speakeasy Grapheasy	Speakeasy	X	X	X		NO	YES	Many	$ 2500/yr	Sophisticated mathematical processing environment with graphics capability. Environment centered around numerical analysis language with many, analysis functions.
	Ctrl-C	Systems Control Technology	X	X	X		NO	YES	Many	$ 10000	CAE environment with plotting capability
	MathScribe	Tektronix									*No response.*

FIGURE 4-6 Summary of Commercial Packages Investigated (Cont'd)

CAN	PROGRAM NAME	VENDOR	TYPE				DATA MANAGE-MENT	APPLI-CATION LANGUAGE	INPUT FILE FORMAT	APPROX PRICE	COMMENTS
			PLOT	MATH	STAT	OTHER					
	DAN (Data ANalyzer) Math++	Triakis	X		X		NO	NO	ASCII	$ 295	Low cost, C-language graphics package. Provides X-Y plots and 2D graphing. Has features for data scaling, shifting, zooming and multiple plots. Has interfaces to C-language function calls.
*	UNIGRAPH-2000	UNIRAS	X	X	X		NO	YES	Many	TBQ	Full featured data analysis and graphics package which includes interface capabilities to INGRES database files. Plot definitions are menu or command driven. Complete 2D/3D data visualization features. No zoom.
	TK Solver Plus	Universal Tech Systems		X	X		NO	YES	Many	$ 995	Equation solver package with interfaces to CAD/CAM software packages.
	SPARSPAK	University of Waterloo		X			NO	NO	Several	$ 700/yr	FORTRAN subroutines for solving large, sparse matrix equations.
	Visual:ProChart	Visual Engineering	X				NO	NO	ASCII	$ 3100	Business graphics interactive system with limited data set size. Offers a wide variety of pie, bar and line chart functions.
	Mathematica	Wolfram	X	X			NO	YES	Several	$ 2400	Symbolic mathematics environment. Provides capability to symbolically solve algebra, matrix, and calculus equations in closed (symbolic) form.

FIGURE 4-6 Summary of Commercial Packages Investigated (Cont'd)

Several commercial CAE packages appear to satisfy these requirements. These packages (and vendors) are as follows:

a. TECPLOT (Amtec, Inc.);
b. RS/1 (BBN Software. Inc.);
c. MATLAB (Mathworks, Inc.);
d. TempleGraph (Mihalisin Assoc.);
e. TECHBASE (MINEsoft Ltd.);
f. PV~Wave (Precision Visuals, Inc.);
g. SAS/Graph (SAS Institute, Inc.); and
h. Unigraph 2000 (Uniras Inc.).

More detailed evaluation and benchmarking of these candidates are recommended.

4.4 SPECIAL APPLICATIONS

4.4.1 Application List and Output

The special applications module consists of diagnostic and data evaluation applications that are primarily procedural in nature. These applications are used to filter test data and identify directly measured operating anomalies and definitive violations of operating specifications. As such, they provide a first cut at the feature identification abilities required in the more sophisticated, heuristic data evaluations to be accomplished in the expert-aided diagnostics module.

Many of these special applications are a part of the current diagnostic procedures. Some of these applications, such as for evaluation of green run data, have even been developed into FORTRAN programs on the Perkin Elmer and are currently in use as individual tools to aid in the diagnostic process. These programs will be ported to the Sun workstation and will be integrated into this diagnostic system. Thus, the current diagnostic procedures will be incrementally enhanced by building upon systems and procedures already in place.

The special applications which have been identified as are:

a. Sensor Data Validation and Signal Reconstruction;
b. Startup Analysis;
c. Shutdown Analysis;
d. Main Stage Analysis;
e. Green Run Analysis; and
f. Steady State Power Balance.

The user will start each of these applications through a menu-driven selection program on the Sun workstation. Each of these applications will operate on data stored in the integrated database.

4.4.2 Special Applications HIPO Analysis

Details of the input data requirements, the process logic and output from each of the special applications will now be presented in the form of HIPO charts.

This application will detect and isolate hard and soft sensor failures in the hot fire data. calibration and scaling errors will also be detected on certain critical parameters. When one of these sensor failure is identified, an estimate of the correct sensor value will be generated and the hot fire data set will be updated.

4.4.2.1.1 Input

A. User request to validate data.

B. User supplied test number to validate.

C. User supplied previous tests for comparison.

D. CADS data for the selected tests.

4.4.2.1.2 Process

The process of the sensor validation task is currently being developed under the Sensor Data Validation Task of the Life Prediction Program.

4.4.2.1.3 Output

A. Validated and Reconstructed PID's.

B. Identification of reconstructed PID numbers.

4.4.2.2 Startup Analysis

This application will calculate critical characteristics of the startup transient (from engine start to engine start plus 6 sec) of the engine. Comparison of the engine start will be made against the start confirm criteria and the two sigma startup database.

4.4.2.2.1 Input

A. User request to perform analysis of startup transient.

B. User specified test number.

C. CADS and Facility data for the test.

D. Start confirmation criteria.

E. Two sigma startup data.

4.4.2.2.2 Process

A. Open CADS and Facility data files for selected test.

B. Open two sigma startup data file.

C. Calculate prime times for:
(1) Fuel pre-burner;
(2) ox pre-burner; and

(3) Main combustion chamber.

D. Evaluate turbine discharge temperature measurements against start conf irm criteria.

E. Examine data for existence of fuel side oscillations.

F. Compare sensor data with two sigma startup values. Report the number of two sigma excursions, the length of time above or below two sigma, and the minimum and maximum excursion from two sigma for each data channel evaluated.

G. Generate temporary file of average values from this test for automated update of sigma values.

H. Generate startup evaluation sheet.

4.4.2.2.3 Output

A. Startup evaluation sheet.

4.4.2.3 Shutdown Analysis

This application will calculate the shutdown characteristics of the engine. Evaluation of the thrust decay rate, purge and valve sequencing will be made against specification requirements. There is currently no two sigma database for shutdown values and development of one was not characterized as a high priority by the diagnostic experts.

4.4.2.3.1 Input

A. User request to perform analysis of shutdown transient.

B. User specified test number.

C. CADS and Facility data for the test.

D. Shutdown specification criteria.

4.4.2.3.2 Process

A. Open CADS and Facility data files for selected test.

B. Calculate thrust decay rate. Compare with specification requirement.

C. Calculate timing of the valve and purge shutdown sequence. Compare with specification requirements.

4.4.2.3.3 Output

A. Shutdown analysis sheet.

4.4.2.4 Mainstage Analysis

This application will compare steady state operation of the engine at all standard power levels with the two sigma data bases. Performance comparisons will be generated for all measurements at standard power levels.

4.4.2.4.1 Input

A. User request to perform mainstage two sigma analysis.

B. User specified test number.

C. CADS and Facility data for the test.

D. Sigma database.

4.4.2.4.2 Process

A. Open CADS and Facility files and sigma database file

B. Locate the point in the test of:
(1) Maximum fuel turbine discharge temperature at 65% RPL;
(2) Maximum fuel turbine discharge temperature at 100% RPL;
(3) Maximum fuel turbine discharge temperature at 104% RPL; and
(4) Maximum fuel turbine discharge temperature at 109% RPL.

C. For each of these test times, calculate:
(1) HPOTP Inlet Pressure, psia;
(2) HPOTP Discharge Pressure, psia;
(3) PBP Discharge Pressure, psia;
(4) LPTOP Speed, rpm;
(5) HPOT Discharge Temp (Ch A), R;
(6) HPOT Discharge Temp (Ch B), R;
(7) HPOP Speed, RPM;
(8) HPFTP Inlet Pressure, psia;
(9) HPFTP Discharge Pressure, psia;
(10) HPFP Discharge Temp, R;
(11) LPFTP Speed, RPM;
(12) HPFTP Speed, RPM;
(13) HPFT Discharge Temp (Ch A), R;
(14) HPFT Discharge Temp (Ch B), R;
(15) 0POV Position;
(16) OPB Pc, psia;
(17) FPOV Position;
(18) MCC coolant Discharge Temp, R; and
(19) MCC coolant Discharge Pressure, psia.

D. Compare these test values with the mean and sigma values stored in the sigma database.

E. Generate the performance comparison report at each power level.

F. Record the average values calculated for each power level in a temporary file for eventual update to the sigma database (to incorporated into sigma database upon user request).

4.4.2.4.3 Output

A. Performance comparison report (see Figure 4-7).

B. Update file for sigma database.

4.4.2.5 Green Run Analysis

This application evaluates the test profile and engine performance against green run specifications and produces preliminary green run summary sheets. This preliminary green run summary sheet is used to determine if the tested component(s) met all green run requirements.

4.4.2.5.1 Input

A. User request to perform green run analysis.

B. User specified test number.

C. Component(s) being evaluated.

D. CADS and Facility data for the test.

E. Green run specification criteria.

4.4.2.9.2 Process

A. Open CADS and Facility files and green run specification file.

B. calculate accumulated time at each power level based on PC.

C. Compare with green run specifications for minimum operating time.

D. Calculate the point in test of:
(1) Minimum NPSP on LAX side at 104% AFL;
(2) Maximum NPSP on LAX side at 104% RPL;
(3) Minimum NP6P on LAX side at 109% RPL;
(4) Maximum NPSP on LAX side at 109% RPL;
(5) Minimum NPSP on Final side at 104% RPL; and
(6) Minimum NP6P on Fuel side at 109% RPL.

E. For each of these six points in the test, determine if NPSP specifications are met.

F. For each of the acceptable NPSP points, calculate:
(1) HPFT discharge temperatures;
(2) Coolant liner delta P;
(3) Coolant liner tem. erature;
(4) Primary ox seal drain pressure;
(5) Intermediate seal purge pressure;
(6) Secondary seal cavity pressure;
(7) Turbine discharge primary seal pressure;
(8 Turbine discharge temperature;

ORGANIZATION: EP-52	MARSHALL SPACE FLIGHT CENTER	NAME: TAYLOR HOOPER
CHART NO.: 1	PERFORMANCE COMPARISON 104% PL, MAX FUEL	DATE: 06/01/90

PARAMETER	PHASE II DATABASE		COMPARISON TO DATABASE	
	AVERAGE	1 SIGMA	A20501DB	N SIGMA
HPOTP INL PRESS, PSIA	367	28	334	-1.18
HPOTP DS PRESSURE, PSIA	4068	27	4050	-0.67
PBP DS PRESSURE, PSIA	7312	137	7297	-0.11
LPOTP SPEED, RPM	5149	53	5181	0.60
HPOT DS TEMP CH A, R	1332	57	1422	1.58
HPOT DS TEMP CH B, R	1355	62	1415	0.97
HPOP SPEED, RPM	28137	419	27968	-0.40
HPFTP INL PRESS, PSIA	233	14	239	0.43
HPFTP DS PRESSURE, PSIA	6175	40	6118	-1.43
HPFP DS TEMP, R	98	2	91	-3.5
LPFTP SPEED, RPM	15858	324	15878	0.06
HPFTP SPEED, RPM	35222	239	34591	-2.64
HPFT DS TEMP CH A, R	1700	62	1608	-1.48
HPFT DS TEMP CH B, R	1721	51	1643	-1.53
OPOV POSITION, %	67	2	66	-0.50
OPB PC, PSIS	5210	35	5170	-1.14
FPOV POSITION, %	82	2	78	-2.00
MCC CLNT DS TEMP, R	461	19	469	0.42
MCC CLNT DS PRESS, PSIA	4504	99	4389	-1.16

09:30 6/1/1990

FIGURE 4-7 Steady State Performance Calculations

(9) HPOTP speed; and
(10) HPOTP PBP Discharge pressure.

G. Prepare specification test results for the appropriate component(s).

4.4.2.5.3 Output

Preliminary green run summary sheets (Figure 4-8 and 4-9).

4.4.2.6 Steady State Power Balance

The steady state power balance is used to perform mass balances and calculate temperatures, pressures and flowrates where direct measurements are not available. From these operating conditions, turbine and pump efficiencies and performance ratios are calculated which can be used to predict the performance of the engine at alternate operating points and standard, rated conditions.

The steady state power balance is a FORTRAN application which is run on the IBM-3084 at MSFC. This application could be ported to the Sun workstation and run locally or access to the IBM-3084 could be provided using the Sun as a terminal.

4.4.2.6.1 Input

A. CADS and Facility data which has been reduced to one second average files.

B. JCL to initiate program execution.

4.4.2.6.2 Process

Refer to the SSME Model Documentation assembled by the Martin Marietta Model Group.

4.4.2.6.3 Output

A. Predicted C2 and Kf constants and rated performance of the engine at standard conditions (see Figure 4-10).

4.5 EXPERT AIDED DIAGNOSTICS

4.5.1 Applications List

4.5.1.1 Features Identification

This application examines transient parameter readings to determine if specific features exist in the data. Features include level exceedances, step shifts, oscillations, decays, etc., which define potentially anomalous engine behavior. Certainty values will be estimated for each potential anomaly identified.

HPFTP	CRITERIA MET
GREEN RUN CRITERIA	
> 250 SECONDS MINIMUM DURATION	✓
> 150 SECONDS MINIMUM AT 104% RPL OR GREATER	✓
> 50 SECONDS MINIMUM AT 109% RPL	✓
> 10 SECONDS MINIMUM LPFP NPSP = 6+2/-0 AT 104% OR GREATER	✓

104% RPL	PRESTART		START		MIN VENT[2]	
	LIMIT	ACTUAL	LIMIT	ACTUAL	LIMIT	ACTUAL
HPFT DS TMP'S	450 MIN	513	800 MAX[1]	646	1810 MAX	1653
COOLANT LINER DELTA P [3]	-	-	325 MAX[4]	168	300 MAX	195
COOLANT LINER TEMP	AMBIENT MAX	542	-	-	500 MAX	326

1) FROM E/S TO E/S +1.75
2) APPLICABLE ONLY IF TESTED AT THIS NPSP
3) DETERMINED BY CLNT LNR PR MINUS MCC HG INJ PR PLUS 100
4) FROM E/S +5 TO E/S +10

109% RPL	PRESTART		START		MIN VENT[2]	
	LIMIT	ACTUAL	LIMIT	ACTUAL	LIMIT	ACTUAL
HPFT DS TMP'S	450 MIN	513	800 MAX[1]	646	1860 MAX	1674
COOLANT LINER DELTA P [3]	-	-	325 MAX[4]	168	300 MAX	197
COOLANT LINER TEMP	AMBIENT MAX	542	-	-	500 MAX	306

NOTE: THIS CHART IS INTENDED FOR QUICK LOOK ANALYSIS ONLY AND SHOULD NOT BE USED TO DETERMINE WHETHER COMPONENTS PASS OR FAIL THE GREEN RUN.

FIGURE 4-8 Green Run Evaluation Report for HPFTP

HPOTP U/N 2306R2 ACCEPTANCE TEST RESULTS

HOT-FIRE TESTING REQUIREMENTS	ACTUAL
250 SECONDS	✓
150 AT A POWER LEVEL ≥ 104% RPL	✓
50 AT A POWER LEVEL = TO 109% RPL	✓
5 AT A LPOTP NPSP = TO 20 (+5/-0)	✓
10 AT AN INLET NPSP = TO 140 (+10/-0)	✓
10 EACH AT 65, 64, AND 63 RPL	✓ / ✓ / ✓

ACCEPTANCE CRITERIA

ENGINE START (T0)

PARAMETER	LIMIT	ACTUAL
PR OX SL DR P	18.0 MAX	15.2 MAX
IMSL PRG P	180 MIN *	190.2 MIN *

* CORRECTED FOR A HELIUM INTERFACE OF 730 PSIA

PEAK TRANSIENT

PARMETER	LIMIT	ACTUAL
PR TUR SL DR P	60.0 MAX	45.3 MAX
SECSL CAV P	31.5 MAX	28.1 MAX

ALL POWER LEVELS

PARAMETER	LIMIT	ACTUAL
PBP DISCH PRESS	NO BISTABILITY	PASS / FAIL

FIGURE 4-9 Green Run Evaluation Report for HPOTP

HPOTP U/N 23[illegible]R2 ACCEPTANCE TEST RESULTS

ACCEPTANCE CRITERIA (CONTINUED)

PARAMETER	104% RPL (ENGINE NPSP 20-25) LIMIT *	ACTUAL *	104% RPL (ENGINE NPSP 140-150) LIMIT	ACTUAL
TUR DS T	1540 MAX	1473 MAX	1470 MAX	N/A MAX
SPEED	29235 MAX	28216 MAX	28685 MAX	MAX
PBP DS P	-		7040 MIN	MIN
PR OX SL DR P	16.0 MAX	14.7 MAX	16.0 MAX	MAX
PR TUR SL DR P	30.0 MAX	21.2 MAX	30.0 MAX	MAX
SECSL CAV P	22.5 MAX	13.4 MAX	22.5 MAX	MAX
TUR DS - PRSL	280 MIN	495 MIN	280 MIN	MIN

PARAMETER	109% RPL (ENGINE NPSP 20-25) LIMIT *	ACTUAL *	109% RPL (ENGINE NPSP 140-150) LIMIT	ACTUAL
TUR DS T	1600 MAX	N/A MAX	1510 MAX	1430 MAX
SPEED	31000 MAX	MAX	30300 MAX	28670 MAX
PBP DS P	-		7515 MIN	7670 MIN
PR OX SL DR P	16 MAX	MAX	16 MAX	14.6 MAX
PR TUR SL DR P	34.0 MAX	MAX	34.0 MAX	20.0 MAX
SECSL CAV P	25 MAX	MAX	25 MAX	13.8 MAX
TUR DS - PRSL	370 MIN	MIN	370 MIN	495 MIN

* APPLICABLE ONLY IF TESTED AT THE STATED NPSP

FIGURE 4-9 Green Run Evaluation Report for HPOTP (Cont'd)

ORGANIZATION: MMC	MARSHALL SPACE FLIGHT CENTER	NAME: TOUCHTON
CHART NO.	SSME MATH MODEL ANALYSIS A2-501/ENGINE 2029	DATE: JUNE 1, 1990

o ENGINE PERFORMANCE EVALUATION

o C_2 RECOMMENDATION:

CURRENT	RECOMMENDED
C_2 = 2.91133 @ 109%	C_2 = 2.9101 @ 109%
C_2 = 2.91376 @ 104%	C_2 = 2.9125 @ 104%
C_2 = 2.91560 @ RPL	C_2 = 2.9143 @ RPL

o K_f RECOMMENDATION:

CURRENT	RECOMMENDED
K_f = 0.8740 @ 109%	K_f = 0.8781 @ 109%
K_f = 0.8784 @ 104%	K_f = 0.8825 @ 104%
K_f = 0.88195 @ RPL AND LOWER PL'S	K_f = 0.8861 @ RPL AND LOWER PL'S

o RATED I_{SP} = 451.77 sec

o REDUCED DATA:

	A2-455	A2-501	DELTA
Isp (sec)	453.34	451.59	-1.75
VACUUM THRUST (lbs)	488170	487034	-1136
TOTAL FLOW (lbm/sec)	1079.65	1081.82	+2.17
LOX FLOW (lbm/sec)	926.20	928.95	+2.75
FUEL FLOW (lbm/sec)	153.45	152.87	-0.58
MR	6.036	6.077	+0.041
SITE THRUST (lbs)	449890	449269	-621

FIGURE 4-10 Steady State Performance Model Report

4.5.1.2 Features-to-Anomalies Generator

This application is a user-friendly input program to allow analysts to capture the reasoning used to isolate specific anomalies from SSME test data. This application will be written using the NEXPERT Object shell. Steps include specification of critical features in certain data channels, associated history or configuration information, and methods for differentiating competing diagnoses.

4.5.1.3 Expert Aided Diagnosis

This application will assist the data analyst in sequentially examining test results presented using predefined plot formats. The application will be written using the NEXPERT Object shell. The application will accept the expert user's judgements concerning the existence and severity of anomalous data features and uses its inference mechanism to suggest failure mechanisms.

4.5.1.4 Advanced Diagnostics

Other approaches to expert aided diagnostics will he hosted by the system. Modules to support other programs such as "deep" reasoning about physical causality can be integrated directly into the workstation structure.

4.5.2 <u>Expert Aided Diagnostics HIPO Analysis</u>

4.5.2.1 Feature Generator

4.5.2.1.1 Input

A. CAD and facility sensor channel data from the current test or flight.

B. Feature database entry for sensor anomalies including the following elements (see Figure 4-11 for typical entry screen layout):
   (1) Sensor channel identifier;
   (2) Operating mode;
   (3) Feature descriptions; and
   (4) Threshold or reference values.

4.5.2.1.2 Process

This application (see Figure 4-12) will automatically analyze test data channels to detect anomalous features:

a. Open feature descriptor table defining data channels and test phases for examination;

b. For each test phase (start, mainstage, and cutoff), access data for channels defined in feature table;

c. For each data channel data set and feature type, (e.g. threshold exceedance, 2-sigma bounds checks or oscillation) call automatic analysis module to perform feature detection;

FEATURE DEFINITION ENTRY

NAME: MCC_LN_CAV_PR

PARAMETERS: MCC LN CAV PR 1 (1951)
MCC LN CAV PR 2 (1952)
MCC LN CAV PR 3 (1953)

FEATURE	PHASE	TEXT	RELATION	REFERENCE
OT	START	UNDERSHOOT OVER 2σ THRESHOLD	ABOVE	2σ
UT	START	BELOW 2σ BAND	BELOW	2σ
DIV	START	SENSOR A/B/C DIVERGENCE	DIVERGE	0.5 PSI
OM	ALL	LEVEL ABOVE MAXIMUM	ABOVE	0.5 PSI

FIGURE 4-11 Typical Entry Screen Layout for Feature Description Table

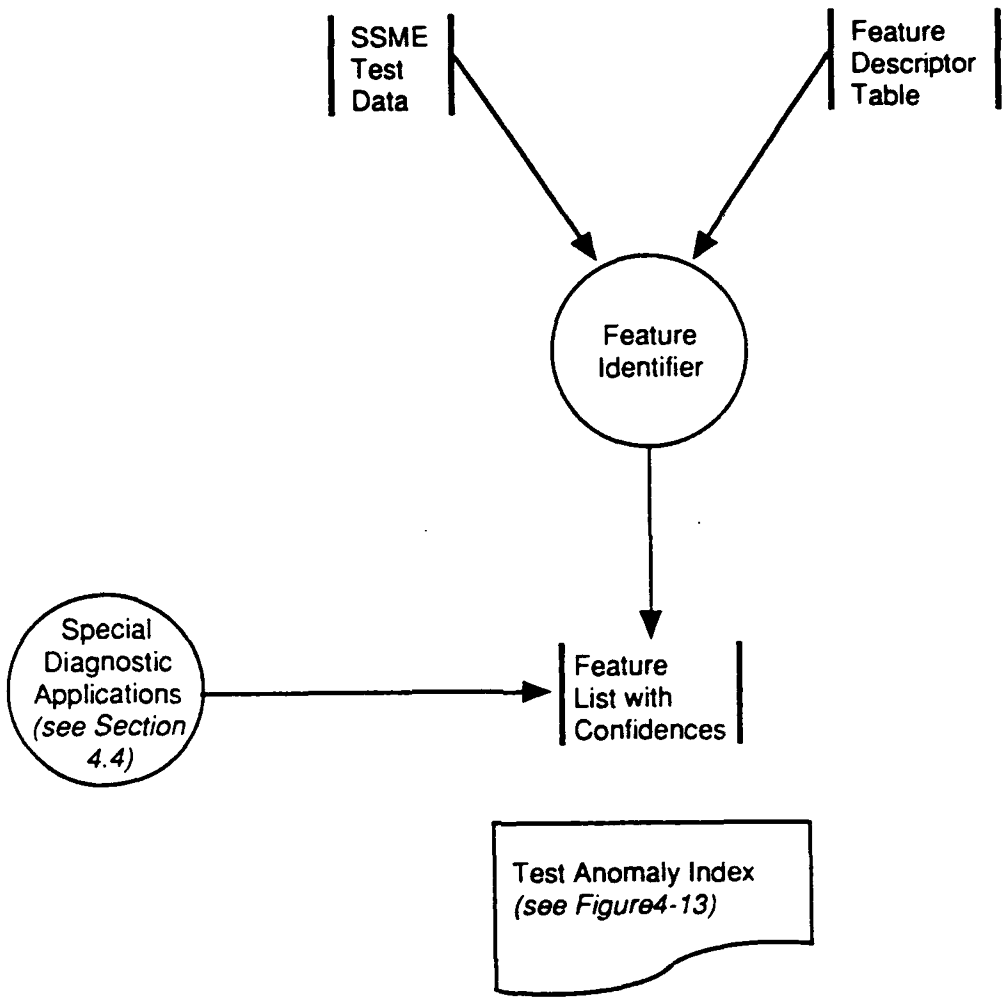

FIGURE 4-12 **The Feature Generator Detects Pre-Defined Characteristics in Test Data and Makes Entries in Feature List**

TEST ANOMALIES INDEX

REF	TEST	DATE	PHASE	PARAMETER	FEATURE	RULES
S1	A2-492	2/13/90	START	MCC LN CAV PR 1	UNDERSHOOT ABOVE 2σ THRESHOLD	YES
S2	A2-492	2/13/90	START	MCC LN CAV PR 3	UNDERSHOOT ABOVE THRESHOLD	YES
M1	A2-492	2/13/90	MAINSTAGE	HPOT DS TMP	CHANNEL A/B DIVERGENCE	NO
M1	A2-492	2/13/90	MAINSTAGE	HPFP IN TEMP	OVERSHOOT ABOVE THRESHOLD	YES
M1	A2-492	2/13/90	MAINSTAGE	PBP DS TMP	INCREASING DURING SS OPS	YES

FIGURE 4-13 **Test Anomalies Index Presents Anomaly Features Detected in the Test Data and Acts as a Menu Index for Subsequent Data Analysis (Typical Format)**

d. Analysis modules will return indication of the existence of features and a confidence level (e.g. measures relating to amount of exceedance, time over limit, and other severity indicators); and

e. For features detected, enter feature symbol (created from feature name, parameter, and feature descriptor e.g. MCC_LN_CAV_PR_1_OT) and confidence into feature list for test and segment. For features defined with "negative reporting", enter feature name with confidence level of feature not existing.

Features detected in the data will be combined in the Feature List with other diagnostic facts derived in the special diagnostic applications (see Section 4.4). The Feature List acts as a blackboard for expert aided diagnosis and advanced diagnostic applications. This blackboard file is maintained as part of the NEXPERT Object file system and exists outside of the integrated database. The blackboard file is the interface between the information in the integrated database and the diagnostic processes implemented in the NEXPET Object shell.

4.5.2.1.3 Output

A. Diagnostic facts derived from the features and written to the blackboard file for each match or partial match of an anomalous feature in a test data channel.

B. Confidence level in each fact based on the number and degree of feature matches between data and reference descriptors.

4.5.2.2 Features-to-Anomalies Generator

This application will generate/update the rulebase of the expert aided diagnostics maintained by NEXPERT Object using tools which are part of the shell. The rules describe the relationships between observed data (i.e. test data, inspection reports, prior test, component history, and component age) and observed hardware failures. The program will capture the experience of the data analyst who discovers and diagnoses a new type of failure or it will update the reasoning path based upon experience with a recognized failure event. The program will be the vehicle for knowledge maintenance and will permit the users of the system to develop and enhance the diagnostic effectiveness of expert aided diagnosis through use of the workstation for data analysis:

4.5.2.2.1 Input

A. Current knowledge (i.e. captured rules) relating the occurrence of anomalous data features to associated hardware or test failures.

B. Expert experience and judgement of the data analyst user.

4.5.2.2.2 Process

A. Open knowledge base (maintained in NEXPERT Object).

B. Select existing or new rule set ("knowledge island") used to process a given anomalous feature.

C. Obtain decision network diagram of rule set to assist in visualization of rule relationships (using NEXPERT Object feature).

D. Update rule base structure relating observed data anomalies with causative hardware failures based upon new knowledge about the meaning of observed features.

E. Define new data features or facts if required.

F. For each rule, define user prompt for fact and a pre-defined plot or report format to be produced when the data display function is selected (at each step, a hot key will permit the user to have access to the test data beginning with a pre-defined plot format for the particular node (see Figure 4-14).

G. On completion of user changes, update the knowledge base file (maintained by NEXPERT Object).

4.5.2.2.3 Output

An updated knowledge base (rule base) describing the relationships between observed anomalies, historical data, maintenance and inspection reports time/life considerations and hardware failures.

4.5.2.3 Expert Aided Diagnostics

The expert aided diagnosis application (resident in the NEXPERT Object shell) uses the knowledge base and features discovered in the test data to control investigation of anomalies and inference concerning the cause (if any) of the problem.

This program uses a "flat" knowledge representation which is based upon heuristic rules rather than reasoning on the physical phenomena causing the feature. At any point in the analysis of events, a list of candidate faults and confidence levels for the test can be displayed to the user. These faults can be influenced by analysis of any feature in the current test. The system will be capable of diagnosing multiple, dependent faults.

4.5.2.3.1 Input

A. The knowledge base (rule base) describing the relationships between observed anomalies, historical data, maintenance and inspection reports time/life considerations and hardware failures.

B. Diagnostic facts for each match or partial match of an anomalous feature in a test data channel or other facts concerning inspection reports, configuration and history.

C. Confidence levels in the facts.

4.5.2.3.2 Process

A. Open Knowledge base files and feature (fact) files maintained by NEXPERT Object shell.

B. Select anomaly or continue with diagnosis of anomaly if previously initiated.

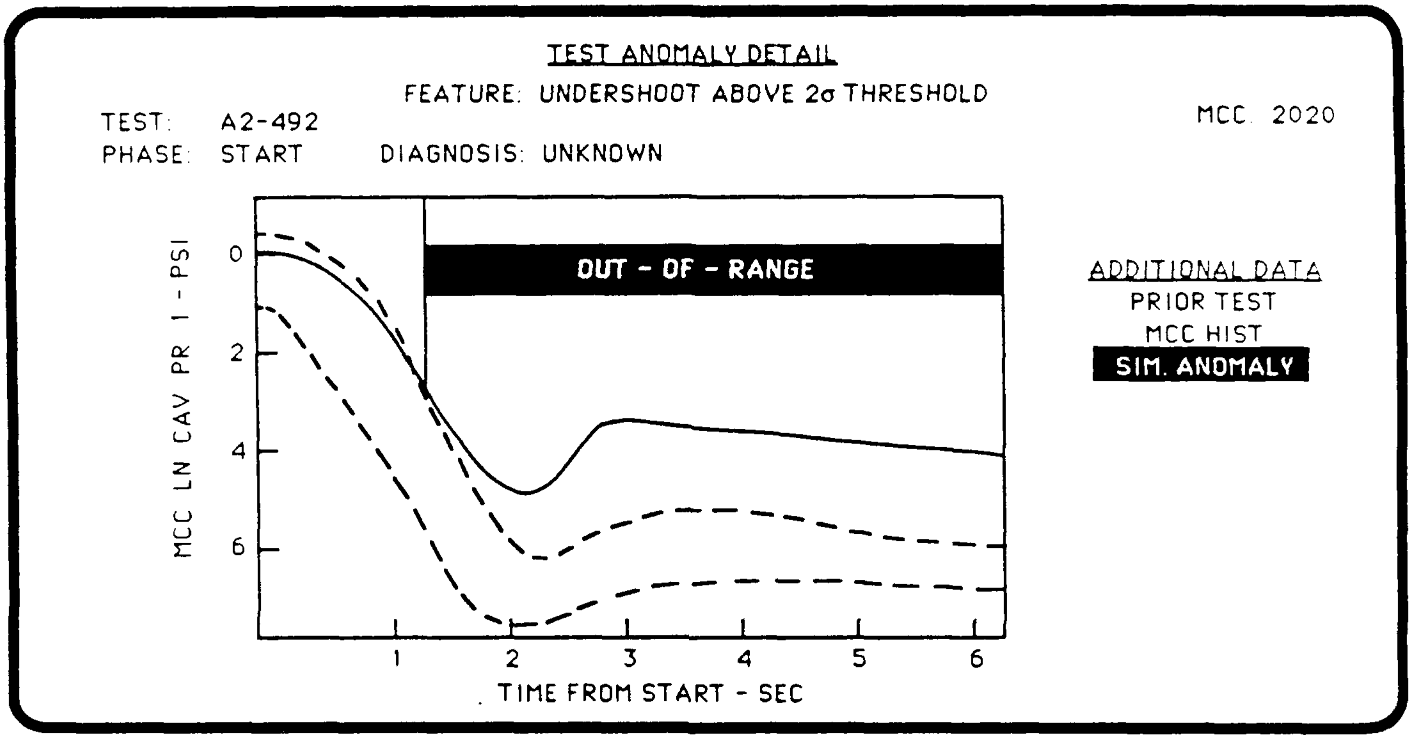

FIGURE 4-14 Pre-Defined Plot Format Is Available During Diagnosis to Show Basis of Feature Detection

C. Perform inference step (back/forward chain). If in "Auto" mode, continue until no more facts can be inferred. If in "Step" mode, halt before firing next rule and allow user options (as follows).

D. On user selection, retrieve pre-defined report for rule. This can be a plot of test data, retrieval on other tables in integrated database or other report containing data related to the rule clauses (for example, see Figure 4-15).

E. On user selection, allow user access to the CAE environment with default selections set to this test, phase, and anomaly.

F. On user selection, suspend diagnosis process and store parameters required to restart process at suspended point. Exit to main menu.

G. On user selection, obtain background information using hypertext help system with entry defined by specific rule being examined and dynamic hypertext indices set up for this test, phase, anomaly, etc. to define context of help. This system can contain dynamic graphics provided by the user interface (DataViews or SL).

H. On user selection, alter state of one or more facts and/or confidences concerning features or intermediate conclusions.

I. On user selection, allow a completed diagnosis to be stored in anomalies database (see Figure 4-16) which contains a history of diagnostic results including follow-up narratives, related inspection reports, etc..

J. On user selection, obtain a window with transaction log tracing the inference process as it has progressed to this point.

K. On user selection, obtain a graphical representation of the inference network showing actual status of inference to this point.

L. Proceed to next inference step.

4.5.2.3.3 Output

A. Diagnosis(es) of hardware or test failure or indication of a "false alarm" based upon reasoning controlled by the rules in the knowledge base.

B. Explanation of reasoning path which lead to the conclusion(s).

C. Other supporting data used to clear the fault or make recommendations concerning its importance and disposition.

4.5.2.4 Advanced Diagnostics (External Applications)

4.5.2.4.1 Input

A. Diagnostic facts for each match or partial match of an anomalous feature in a test data channel or other facts concerning inspection reports, configuration and history.

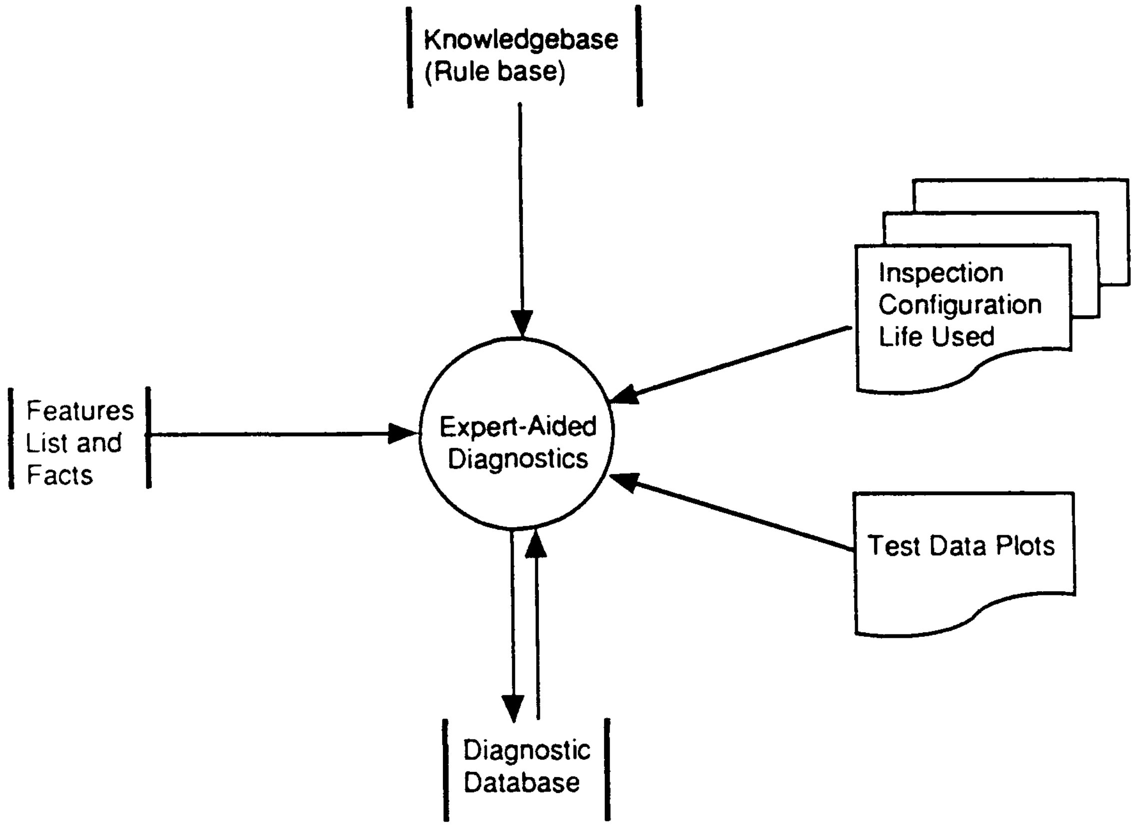

FIGURE 4-15 **Expert Aided Diagnostics Provides a Rule Controlled Analysis of Test Data and Related Information**

HISTORY OF SIMILAR ANOMALIES

PARAMETER: MCC LN CAV PR

ANOMALY: UNDERSHOOT ABOVE 2σ THRESHOLD

REF	TEST	DATE	PHASE	DIAGNOSIS
S1	A1-242	1/12/88	START	FACILITY PURGE REQUIRED
S2	A2-296	2/20/89	START	FACILITY PURGE REQUIRED
S3	A1-347	4/17/89	START	MCC LN CAV SENSOR FAULT
S4	A2-310	5/30/89	START	UNKNOWN
S5	A2-395	10/10/89	START	FACILITY PURGE REQUIRED
S6	A2-400	11/1/89	START	FACILITY PURGE REQUIRED

FIGURE 4-16 Completed Diagnoses Are Incorporated into Integrated Database

B. Confidence levels in the facts.

C. Other files dependent upon the external application.

4.5.2.4.2 Process

The workstation allows integration of externally generated applications (using the NEXPERT Object shell) to perform additional, focused diagnostics using information available from the integrated databases and interfacing with the fact (blackboard) files. For example, a deep reasoning inference model could be used to detect and isolate problems in the HPOTP using the internal thermodynamic relationships of the hardware. Applications of this type could use the expert system/CAE environment established by the workstation to obtain data and additional, related information. The interface between applications could then be implemented in a seamless manner with little impact on the user interface.

4.5.2.4.3 Output

A. Diagnosis(es) of hardware or test failure or indication of a "false alarm" based upon reasoning controlled by the rules in the knowledge base;

B. Explanation of physical reasoning used to derive failure diagnosis using "deep" inference methods; and

C. Other supporting data used to clear the fault or make recommendations concerning its importance and disposition.

4.6 SYSTEM ADMINISTRATION

4.6.1 Database Administration

Database administration will be performed using file maintenance programs included in Ingres. Functions will include data dictionary modification, data table edits, and table loading. Additionally, pre-defined plot formats will be maintained by the database administrator so that standard plot sets can be produced by each workstation for each test. Local definition of pre-defined plot formats will be the responsibility of individual analysts.

4.6.2 Database Backup/Recovery

Data backup and recovery will utilize programs incorporated in the SUN and VAX processor platform workstations. File server backups will protect data from short term loss. Long term file backups will be based upon PE4 mass storage. Workstation data backups and recovery will be the responsibility of local analysts using existing workstation utilities.

4.6.3 System Installation/Reconfiguration

Software installation, reinstallation and reconfiguration will be controlled by this program. In addition to customizing the workstation programs to the analysis functions of the specific workstation, the program will install Ethernet vLAN programs necessary for system operation.

4.6.4 System Security

System security will be provided to prevent unauthorized use of the system and to restrict write priveledges to the integrated databases and the diagnostic rule modules. The system will require a user password to enter the main diagnostic system menu. This password, in addition to restricting user access, will also determine the user priveledges. Specific user priveledge will be required to edit the contents of the integrated database and to modify the diagnostic rule base. The password system will be maintained by the database administrator.

Simultaneous access to data by multiple users will be controlled by file and record locking utilities provided under Ingres.

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5.0 IMPLEMENTATION PLAN

Diagnostic workstation implementation will be incremental to maximize user input during the expert system software design and assure that the initial benefits of the system reach the user as quickly as possible.

The implementation program is split into three phases (see Figure 5-1). Each phase results in increased system capability, and will permit evaluation and comment by the users. During this evaluation period, design adjustments can be made and software revisions performed that will protect the overall program schedule. At the end of each evaluation period, the software for that increment will be frozen in preparation for upgrade in the subsequent phase. At the completion of the program, the workstation software will be validated and ready for installation at multiple MSFC analysis locations.

In the first phase, the work effort will be directed to establishing the integrated database environment on the networked workstation. The applications described in Section 3.4.2.1 and 3.4.2.2 will be implemented during this phase. Commercial graphics, data analysis and statistics packages will be integrated into this environment and the basic "toolbox" capabilities provided. An evaluation workstation will be installed at MSFC for evaluation by the systems group. During the phase I period, users will access data from SSME tests and maintain historical and configuration files within the system. At end of the evaluation, the integrated CAE environment should be fully established and data access validated.

In the second phase, special application programs, described in Section 3.4.2.3, will he integrated into the CAE environment. The applications include automated diagnostic routines for SSME test phases, two-sigma exceedance packages, analytical redundancy and power balance model integration. These functions will be specified in the software design, implemented and tested in the development environment and then installed in the evaluation platform for user operation. Again, user comments will be incorporated into the functionality. At the end of the evaluation period this portion of the workstation software will be validated.

The last phase of the implementation will involve integration of expert-aided diagnostics into the enhanced CAE environment using applications described in Section 3.4.2.4. The design of the knowledge base and the procedural elements of the system will benefit from user experience with the incremental workstation functions and the acquisition of expert knowledge will be significantly more productive under these circumstances. The expert system software will be specified, including the knowledge bases and integrated into the evaluation system. Additional software being developed for SSME applications under other programs such as the HPOTP diagnostic and health assessment system could be integrated into the workstation environment during this phase. Finally, there will be an evaluation period during which the users will be supported to adjust and enhance the operation of the system and tailor it precisely to their requirements.

At the completion of the effort, the workstation applications will have been fully validated and the software will be ready for installation at multiple locations at the data analysis site.

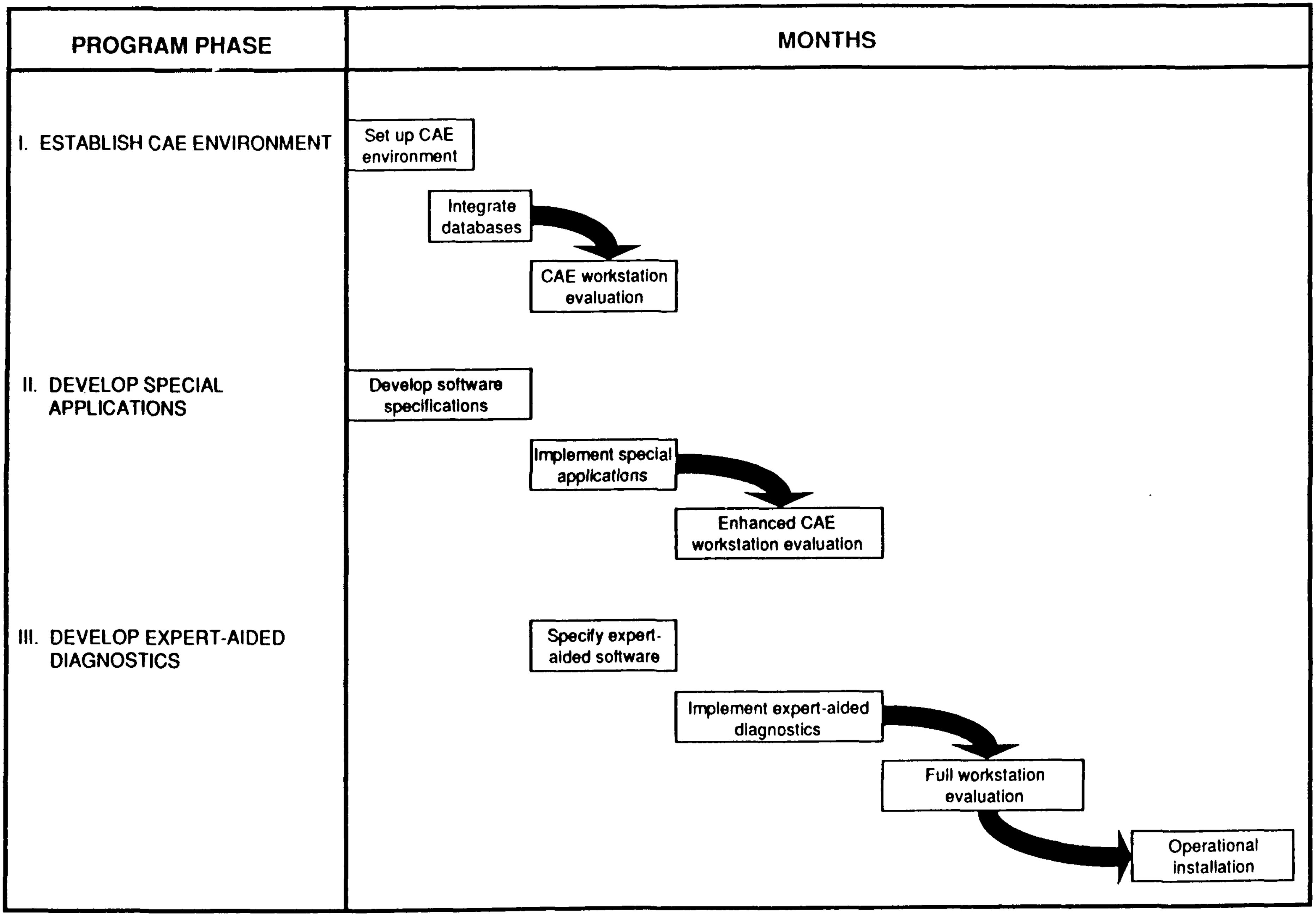

FIGURE 5-1 Health Assessment Workstation Implementation Plan